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A Speciation Modeling Study of Heavy Metal Adsorption to Plastic in Municipal Wastewater Treatment Plant Units

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A SPECIATION MODELING STUDY OF HEAVY METAL ADSORPTION TO PLASTIC IN MUNICIPAL WASTEWATER TREATMENT PLANT UNITS

BY

KAITLYN HAGUE

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THESIS ACCEPTANCE PAGE

Kaitlyn J Hague

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CONTENTS

ABBREVIATIONS

- ABS- Acrylonitrile Butadiene Styrene
- Al- Aluminum
- ALK- Alkalinity
- ASA- Acrylonitrile Styrene Acrylate
- BOD- Biological Oxygen Demand
- Br- Bromide
- Ca- Calcium
- CA- Cellulose Acetate
- Cd^{2+}- Cadmium
- CE- Changjiang Estuary
- Cl- Chloride
- Co- Cobalt
- CO3- Carbonate
- CPE- Chlorinated Polyethylene
- Cr- Chromium
- Cr_2O_{24}- Dichromate Ion
- Cu^{2+}- Copper
- Cw- Concentration of Metal Ion Adsorbed
- DDT- Dichlorodiphenyltrichloroethane
- DEHP- Bis-2-Ethylhexyl Phthalate
- DOC- Dissolved Organic Carbon
- DOM- Dissolved Organic Matter

- EA- Ethylene Acetate
- ECS- East China Sea
- EP- Ethylene-Propylene
- EPM- Expanded Polystyrene
- EVA- Ethylene-Vinyl Acetate
- EVOH- Ethylene Vinyl Alcohol
- F- Fluoride
- Fe- Iron
- GPGP- Great Pacific Garbage Patch
- H^+- Hydrogen
- HDPE- High-Density Polyethylene
- HPE- High Crystallinity Polyethylene
- IC- Ion Chromatography
- k- Freundlich Model Coefficient
- K- Potassium
- L/S- Liquid to Solid Ratio
- LDPE- Low-Density Polyethylene
- LPE- Low Crystallinity Polyethylene
- MFi- Microfibers
- Mg- Magnesium
- Mn- Manganese
- MP- Microplastic
- MPa- Microparticles

- n- Freundlich Model Coefficient
- Na- Sodium
- NH4- Ammonia
- Ni- Nickle
- NO2- Nitrite
- NO3- Nitrate
- OCP- Organochlorine Pesticides
- OH- Hydroxide
- PA- Nylon
- PAH- Polycyclic Aromatic Hydrocarbons
- Pb^{2+}- Lead
- PBDE- Polybrominated Diphenyl Ether
- PC- Polycarbonate
- PCB- Polychlorinated Biphenyls
- PE- Polyethylene
- PES- Polyethersulfone
- PET- Thermoplastic Polyester
- PEUR- Polyether Urethane
- PF- Phenol Formaldehyde
- Phe- Phenanthrene
- PMDS- Polydimethylsiloxane
- PMMA- Poly (Methyl Methacrylate)
- PO4-Phosphate

- POP- Persistent Organic Pollutants
- PP- Polypropylene
- PPC- Polypropylene Carbonate
- PS- Polystyrene
- PTFE- Polytetrafluoroethylene
- PU- Polyurethane
- PUR- Polyurethane
- PVA- polyvinyl Alcohol
- PVC- Polyvinyl Chloride
- q- Concentration of Metal Ion Adsorbed
- R- Freundlich Model Coefficient
- SAM- Styrene Acrylonitrile
- Sd- Standard Deviation
- SO4- Sulfate
- TOC- Total Organic Carbon
- UV- Ultraviolet
- WEERC- Water and Environmental Engineering Research Center
- WWTP- Wastewater Treatment Plant
- Zn- Zinc
- µS- microsiemens

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ABSTRACT

A SPECIATION MODELING STUDY OF HEAVY METAL ADSORPTION TO PLASTIC IN MUNICIPAL WASTEWATER TREATMENT PLANT UNITS

KAITLYN HAGUE

2021

Microplastics are an emerging concern due to their harmful effect to organisms and their ability to facilitate transport of contaminants including heavy metals. Microplastics can enter the environment through wastewater treatment plants, landfill leachate, and littering. Once in the environment microplastics can be distributed throughout rivers, the ocean, and lakes. In order to understand the adsorption of heavy metals to microplastics a geochemical modeling study was completed using Visual Minteq. Lab tests were completed to better understand what constituents are available in wastewater at four different locations: influent, clarifiers, digesters, and effluent. These constituents were then used to observe how adsorption of lead to plastic was affected under different conditions. The conditions that were tested were: without any additions, with DOC present, with DOC and lead present, with DOC, lead, and a plastic adsorption surface present, with lead and a plastic adsorption surface present, with lead, and a pH sweep. It was concluded that lead can be affected by both DOC and a plastic adsorption surface but the adsorption to plastic is not affected by DOC. Additionally, it was discovered the pH does not affect adsorption of lead to a plastic surface, but instead more species occur at a high pH reducing lead's concentration.

1. INTRODUCTION

1.1. Overview

As plastics become widely used across the world by various industries the formation and pollution of microplastics becomes an emerging concern. For plastic particles to be considered microplastics the plastic particle is typically less than 5mm in diameter (Zhang et al., 2016; Zou et al., 2020; Huang et al., 2020; Wilson et al., 2021). One source of these microplastics is wastewater. While wastewater treatment plants (WWTPs) do an excellent job at removing larger macroplastics, these plants struggle to remove the small microplastics (Cole et al., 2011). Microplastics are small enough, that they can seep past most filtration techniques and are strong enough to survive throughout the digestion processes in wastewater treatment. Microplastics additionally can adsorb and desorb harmful contaminants. These containments can include heavy metals that exist in the WWTP. Since microplastics can adsorb these heavy metals, they can also carry the heavy metals into the environment.

This ideology is what lead to the geochemical modeling study that was completed in this thesis. The literature review will explain the microplastic pollution ideology in more depth. The materials and methods, results, and discussion will further explain the completion of the geochemical modeling study.

1.2. Thesis Objectives

The first objective of the aforementioned thesis is to explain the environmental impact of microplastic pollution. The second objective is to complete a comprehensive

speciation modeling study on simulated WWTP units. The third objective is to analyze the results of the geochemical model to promote future work.

1.3. Scope of the Study

The scope of this study was to explain the hazards of microplastic pollution and to analyze the results of the geochemical model: Visual Minteq. The creation, definition, adsorption/desorption properties, and the hazards of microplastics are explained in the literature review. For this study initial measurements of wastewater constituents were found. Then the geochemical model was studied for the speciation of the constituents, the effect of a plastic adsorption surface when lead is added to the water, and the effect of pH on adsorption.

1.4. Thesis Arrangement

This thesis is divided into six distinct sections: the literature review, materials and methods, results, analysis and discussion, and conclusions. The literature reviews explain in depth a review of the literature to explain the emerging concern of microplastics and adsorption/desorption. The materials and methods explain the lab tests that were completed to find the wastewater constituents and how to use Visual Minteq. The results show the results from the various Visual Minteq runs, specifically the constituents that are present, the effect of a plastic adsorption surface, and the effects of pH. The analysis and discussion further explain the previous results. Finally, the conclusions describe the final conclusions gathered from this study and suggestions for future work.

2. LITERATURE REVIEW

2.1. Hazards of Microplastics

Plastics are present in everything from fishing gear, to manufacturing, and engineering to children's toys. Throughout recent years due to plastic material's undeniable strength and resiliency, plastics have become an integral part of several industries. This results in an exceedingly large amount of plastic waste. Even though plastics are admired for their strength when used in products, this results in the plastic's ability to survive in the environment for years.

Approximately 4.6% of all plastics that are created culminate in the ocean (Zhang et al., 2016). These plastics are innately harmful for several reasons.

> "Large items of aquatic plastic debris are recognized as a physical hazard through several mechanisms including entanglement, ingestion, and smothering (Rochman, 2013, p. 2439)."

Plastics in the oceanic environment has been an emerging concern since the 1970s (Cole et al., 2011). Through entanglement, ingestion, and smothering an assortment of aquatic wildlife have died. These large plastic debris are also harmful to coral reefs and other aquatic environments. Additionally, larger plastics will degrade into smaller particles called microplastics.

Microplastics are harmful to aquatic wildlife due to multiple reasons. Microplastics are plastic particles that are smaller than 5mm in diameter (Zou et al., 2020; Zhang et al., 2016). This small size allows microplastics to be bioavailable to organisms (Cole et al., 2011). Bioavailable is:

> "the degree and rate at which a substance (such as a drug) is absorbed into a living system or is made available at the site of physiological activity (Merriam-Webster)."

Since microplastics are bioavailable to organisms, the small particles can, "bioaccumulate in the cells and tissues of invertebrates and vertebrates (Rochman, 2013, p. 2439)." Bioaccumulate is:

> "the accumulation over time of a substance and especially a contaminant (such as a pesticide or heavy metal) in a living organism (Merriam-Webster)."

When microplastics are consumed by organisms they can be toxic in a variety of ways. Firstly, the ingredients of plastics are extremely toxic.

> "Plastics are synthetic organic polymers, which are derived from the polymerization of monomers extracted from oil or gas (Cole et al., 2011, p. 2588)."

Many plastics such as PVC and bisphenol-A have monomers and chemical additives that can be toxic in their makeup (Rochman, 2013). Additionally, plastics often have plasticizers that are added to their composition to extend the life span of the plastic (Cole et al., 2011). The chemicals from these plasticizers can leach into the environment (Cole et al., 2011). The monomers and additives in these plasticizers and other stabilizers in plastics can cause endocrine disrupting effects in living organisms (Zhang et al., 2016). A large number of plastics have components that are hazardous in accordance with the UN's Globally Harmonized System (Rochman, Hentschel, & Teh, 2014).

Secondly, microplastics are harmful due to their ability to adsorb contaminants. Microplastics have the ability to adsorb harmful metals, chemicals, and organic pollutants. This adsorption characteristic allows microplastics to transport the contaminants throughout the environment. Additionally, since microplastics are bioavailable to organisms, the microplastics can bioaccumulate within organisms and leach contaminants. (Rochman, Hentschel, & Teh, 2014; Cole et al., 2011; Rochman, 2013; Zhang et al., 2016)

The previously mentioned microplastics can enter the environment through a variety of ways including wastewater, landfill leachate, and plastic littering. The following study will focus on how microplastics can enter the environment from wastewater treatment plants. Additionally, this thesis will study how microplastics can adsorb heavy metals, particularly lead, within wastewater treatment plants which can then be carried out to the environment. The purpose of the further analysis is to determine the fate of lead with or without plastics in a wastewater system.

2.2. Literature Review Objectives

The first objective of this literature review is the fate and transport of microplastics in the environment. The second objective is to explain the adsorption and desorption properties of metals to plastic particles.

2.3. Composition of Microplastics

Microplastics can be described as fragments: “Plastic debris undergoes degradation in the marine environment producing smaller fragments, some of which are microscopic in size, and which are described as “microplastics” (Bakir et al., 2014, p.

16).” For plastic particles to be considered microplastics the plastic particle is typically less than 5mm in diameter (Zhang et al., 2016; Zou et al., 2020; Huang et al., 2020; Wilson et al., 2021). However according to Cole et al. in, “Microplastics as contaminants in the marine environment: A review,” there is a need to create a standard for microplastic size due to the fact that it can change from case to case (Cole et al., 2011). According to Golwala et al., there are several other categories for plastic sizing other than microplastics:

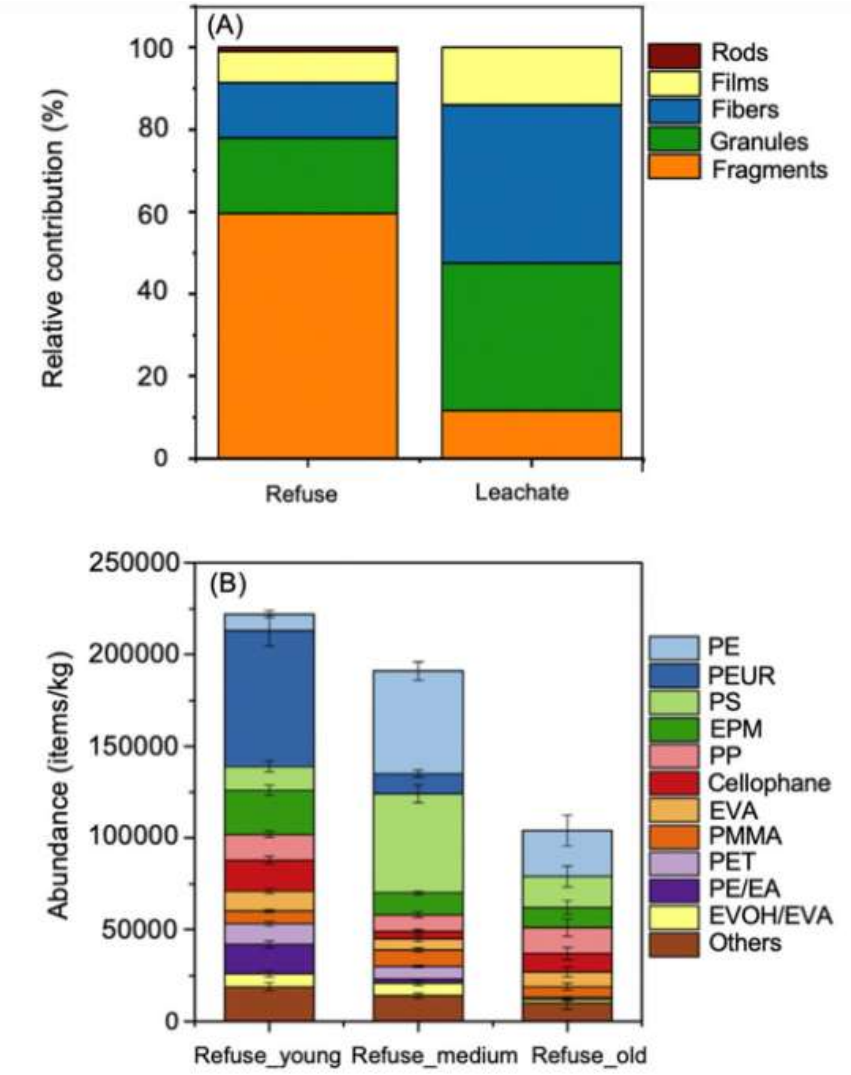
> “Based on size, plastics can be divided into macro– (>25 mm), meso–(<25–5 mm), micro–(5 mm to0.1μm) and nano–(<0.1μm) plastics (Golwala et al., 2021, p. 2).”

The National Oceanic and Atmospheric Administration (NOAA) has agreed that microplastics are plastics that are smaller than 5mm in diameter (Bakir et al., 2014).

Microplastics can be found in several different shapes. These shapes generally fall into one of five shape categories: flakes, fragments, lines, foams, and pellets (He et al., 2019; Golwala et al., 2021). These shapes and the overall size of microplastics can impact how they behave in the environment (Golwala et al., 2021). To better understand what the composition of microplastics may look like see Figure 1. Figure 1 shows the makeup of the microplastics that can be found in refuse and leachate. This figure shows what a snapshot of microplastic shapes and plastic types that may be present in the environment.

Figure 1.

The Composition of Microplastics Found in Refuse and Leachate



Note: Adopted from figure 2 in "Solid waste: An overlooked source of microplastics to the environment (Golwala, et al., 2021)."

Abbreviations: PE- Polyethylene, PEUR- Polyether Urethane, PS- Polystyrene, EPM- Expanded Polystyrene, PP- Polypropylene, EVA- Ethylene-Vinyl Acetate, PMMA- Poly (Methyl Methacrylate), PET- Thermoplastic Polyester, EA- Ethylene Acetate, EVOH- Ethylene Vinyl Alcohol

Microplastics can be further categorized into primary and secondary microplastics. Primary Microplastics are microplastics that are intentionally produced within the size range of microplastics. Secondary microplastics are microplastics that are present from the weathering of larger plastic pollution (Golwala et al., 2021; Waller et al., 2017; Cole et al., 2011).

Examples of primary microplastics include plastic pre-production pellets, cosmetic microbeads, air-blasting media and even glitter (Cole et al., 2011; Golwala et al., 2021). Pre-production pellets are one of the most common forms of primary microplastics. Pre-production pellets are the raw plastic pellets that are melted and molded to create plastic products (Ashton et al., 2010). These pellets usually consist of polyethylene (PE) or polypropylene (PP) and have a 2–5 mm diameter (Ashton et al., 2010). Additionally, pre-production pellets can be a variety of colors or colorless and can be a variety of rounded shapes (Ashton et al., 2010).

While primary microplastics are sometimes limited to pre-production pellets and cosmetic microbeads, secondary microplastics can originate from a variety of sources. This is due to the fact that secondary microplastics are created from,

> "the breakdown of macro- and meso-plastics through photo-oxidative, mechanical, chemical, and/or biological interactions (e.g., microfibers produced from synthetic clothing) (Golwala et al., 2021, p. 2)."

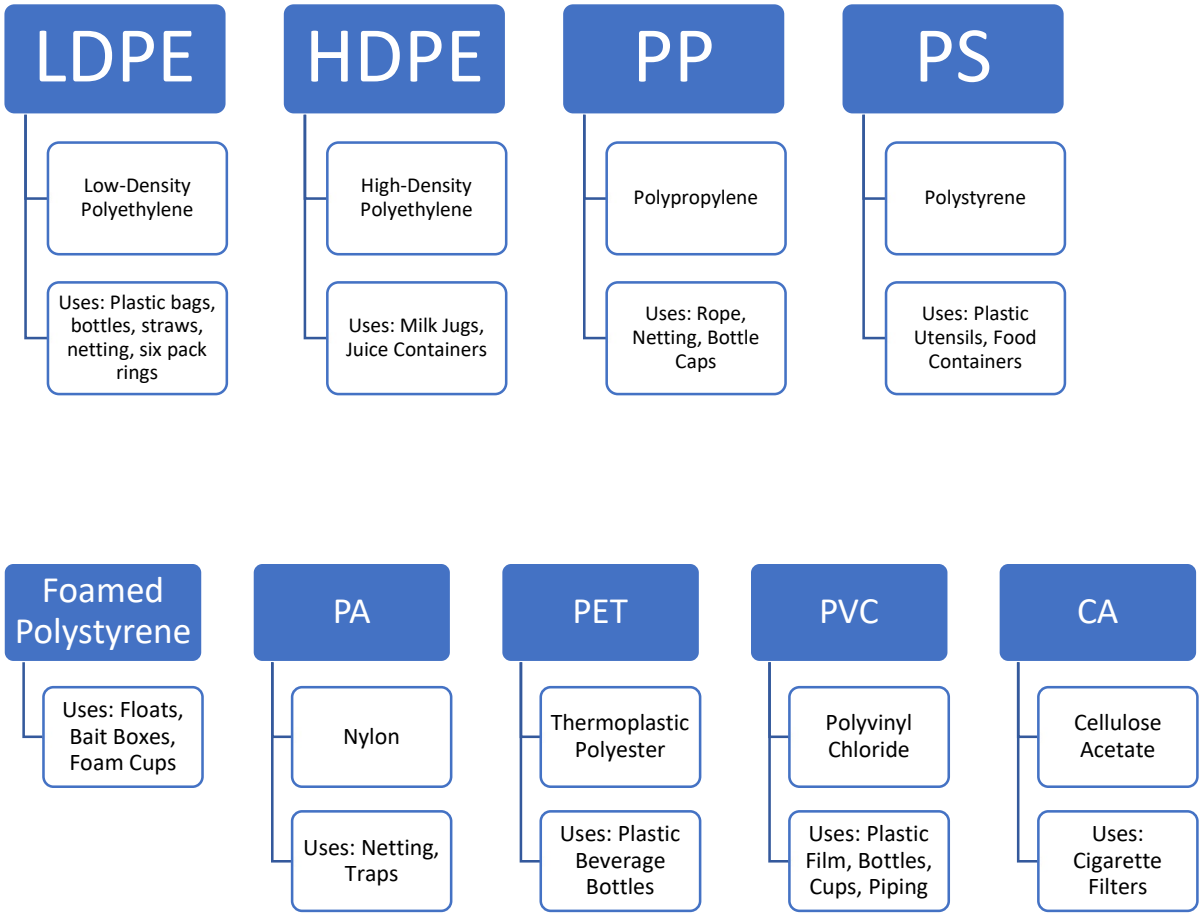
Due to the source of secondary microplastics being so broad, a larger portion of the total microplastic population is comprised of secondary microplastics than primary microplastics (Waller et al., 2017).

2.4. Microplastics in the Environment

Several different types of plastics contribute to the microplastic volume that is present in the environment. Figure 2 shows the common types of plastic that are present in the environment and what their uses in industry are (Andrady, 2011). These plastics tend to be more common in the environment due to their sources. The plastics listed in Figure 2 can be present in the environment in a variety of forms. Microplastics can be present in the environment in both fibers and fragments. Fibers are long thin strands of plastic that often result from clothes being washed or produced. Fibers a large portion of overall microplastic volume. In Zhao et al.'s study on microplastics in the Changjiang Estuary, over 75% of overall microplastic volume was attributed to fibers (Zhao et al. 2019).

Figure 2.

Plastic Types, Abbreviations, and Uses

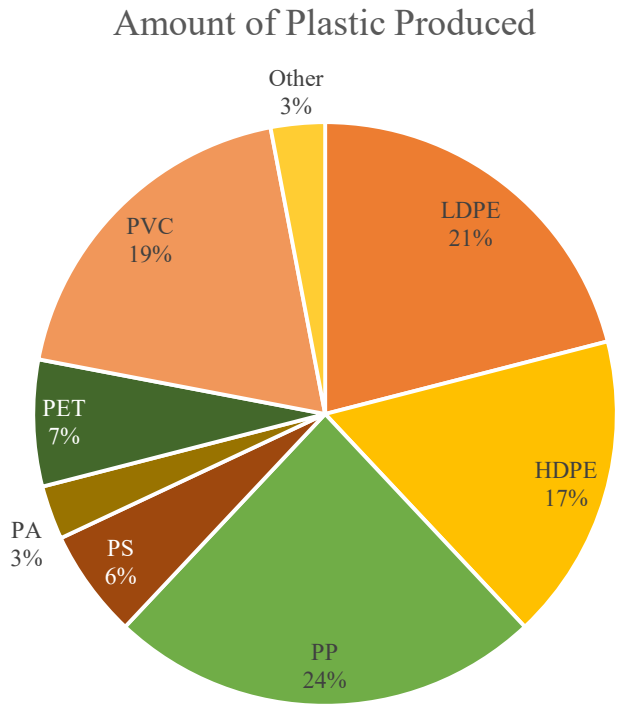


Note: Adopted from Table 1 in, "Microplastics in the Marine Environment (Andrady, 2011)."

2.5. Properties of Each Plastic

Figure 3.

Amount of Plastic Produced



Note: Percentages of plastics produced in industry as adopted from Table 1 in Andrady, 2011.

As shown in Figure 2 there are several different types of plastics. For example, LDPE is used in products such as plastic bags or drinking straws (Andrady, 2011). HDPE and PP are used in milk containers and nets respectively (Andrady, 2011). PS is common due to its uses in disposable utensils and containers that are used for food (Andrady, 2011). Other disposable products such as plastic drinking bottles usually use PET (Andrady, 2011). PVC is found in several uses including construction piping, bottles, or other building materials (Andrady, 2011). PE and PP are commonly used in fishing gear, which allows them to be easily deposited in the ocean (Andrady, 2011). Figure 3 displays

the percentage of production of each plastic. This figure allows one to understand how common each plastic is to exist in the environment.

The composition of each plastic can additionally impact a plastic's ability to exist in the environment. Additionally, the composition of a plastic can contribute to its overall toxicity. Plastics that have a high molecular weight such as PVC will often remain in the environment due to the absence of microbial species to metabolize these plastics (Andrady, 2011). Toxicity that can be present in a plastic's composition can be accredited to a variety of factors. Plastics often have toxic additives such as phthalate plasticizers that are present in PVC. As plastics degrade, they can emit intermediate polymers and aromatics that can be toxic. Finally, plastics are known to adsorb harmful contaminants which can become bioavailable to organisms (Andrady, 2011). This fact of a plastics adsorption is the basis of this literature review.

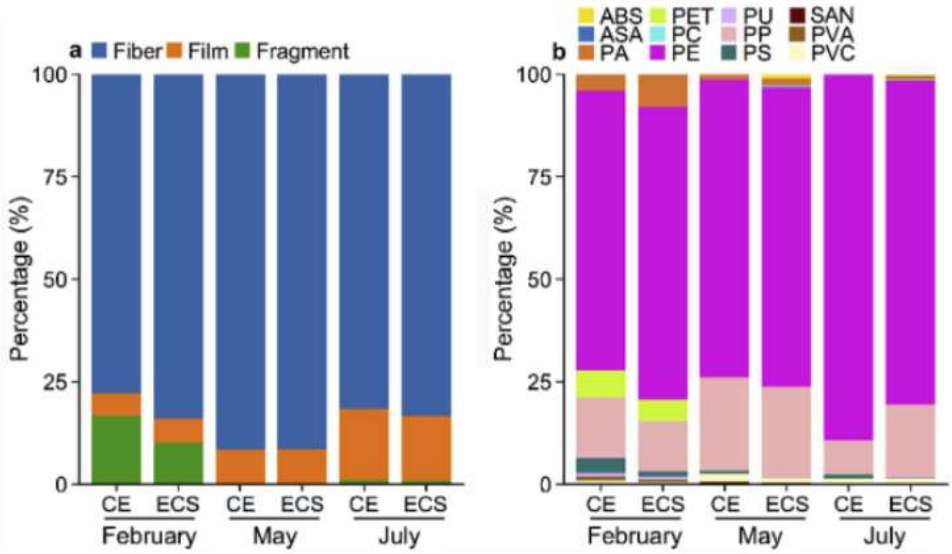
2.6. Likeliness of Each Plastic to Occur in the Environment

The aforementioned plastics are all prone to occur in the environment in different amounts, and in different conditions. As shown in Figure 2 plastics are used for a variety of uses in daily operations. This is due to the fact that plastics are light-weight and extremely durable for their cost (Andrady, 2011). Additionally, this allows plastics to be used in a variety of packaging ang single-use applications (Andrady, 2011). While some plastics that are used can be recycled or are deposited in landfills a large portion of plastics appear in the world's water systems. The shape, use, size, and amount of each plastic type assists in determining if the plastic will end up in water systems in the form of microplastics and at varying amounts (Golwala et al., 2021). Figures 2 and 3 show the amount of each type of plastic produced and how they are used in the environment

(Andrady, 2011). PP and PE are some of the most commonly used plastics (Lebreton et al., 2018; Ashton et al., 2010). In addition to PP and PE, PS, PET, and PVC and other plastics that are used in the packaging industry have a great tendency to enter the ocean due to their immense amount of use (Andrady, 2011). Zhao et al. completed a study of the microplastics present in the Changjiang Estuary (Zhao et al., 2019). Zhao et al.'s study allows for a snapshot of what the morphology of microplastics may look like with in rivers or the ocean (Zhao et al., 2019). The Changjiang Estuary provides an excellent snapshot due to the fact that this river is one of the biggest rivers in the world and exists in an area with a high population (Zhao et al., 2019). Figure 4 shows this snapshot of the morphology of microplastics in the Changjiang Estuary (Zhao et al., 2019).

Figure 4.

Microplastic Composition of Changjiang Estuary



Note: The contents of the microplastics found in the Changjiang Estuary from a study completed by Zhao et al. in 2019. (a.) the shape of the microplastics found. (b.) the plastic type of the microplastics found.

Abbreviations: CE= Changjiang Estuary, ECS= East China Sea, ABS= Acrylonitrile Butadiene Styrene, PET= Thermoplastic Polyester, PU=Polyurethane, SAN=styrene acrylonitrile, ASA= Acrylonitrile Styrene Acrylate, PC= Polycarbonate, PP= Polypropylene, PVA= Polyvinyl Alcohol, PA= Nylon, PE= Polyethylene, PS= Polystyrene, PVC= Polyvinyl chloride

The different sources that contribute microplastics additionally contribute different plastic types. For example, landfill refuse often includes PE, PP, PS, expanded polystyrene (EPM), and polyether urethane (PEUR) (Golwala et al., 2021). He et al. found in their study 17 different types of microplastics in landfill leachate including:

> "PE (34.94%), PP (34.94%), PVC (0.32%), PS (4.99%), ABS (0.32%), PET(5.96%), PUR (1.45%), EVA (0.64%), PA (0.64%), PES (2.74%), EP(0.32%), PF (0.16%), PPC (0.16), PMMA (0.32%), ALK (4.35%), PMDS(2.25%), PTFE (5.48%) (He et al., 2019, p. 40)."

Table 1 from Golwala et al.'s additionally shows the different plastic types found in landfill leachate across the world (Golwala et al., 2021).

Sludge from wastewater treatment plants also contains PE and PP and other low-density microplastics such as polyethylene-terephthalate (Golwala et al., 2021). Table 2 from Golwala et al.'s article shows the different plastic types found in wastewater sludge across the world.

In addition to landfill leachate and wastewater sludge, microplastics are also introduced to the environment through littering. Beach littering and fishing often result in microplastics of various plastic types entering the ocean but most commonly PE and PP (Andrady, 2011).

Table 1.

Landfill Leachate Microplastic Information

Table 1
Microplastics concentration, composition, size, and shapes in landfill refuse and leachate.

Location	Location specification	Microplastics concentration	Microplastics composition	Microplastics size range	Microplastics shape	Reference
China	MSW landfill refuse	20,000–91,000 items/kg	PE, PP, PEUR, PS, EPM	0.23–4.97 mm	Fragment, fiber, film, granule, rod	(Su et al., 2019)
	MSW landfill leachate	0.4–24.6 items/L	Cellophane, PE, PP, PS	0.07–1 mm	Fragment, fiber, flake, granule	(He et al., 2019; Su et al., 2019)
Nordic countries	MSW & IW & mixed landfill leachate	Untreated: 0–4.5 items/L Treated: 0–0.3 items/L	PE, PUR, PET, PS, PP, PMMA, PVC, PA	0.1–0.5 mm	Fiber	(Kilponen, 2016; Praagh et al., 2018)
Thailand	Landfill leachate	13.5–27.5 items/kg	PE, PP, PET	–	Fiber, film, granule, irregular	(Puthcharoen, 2019)
	Landfill refuse	86.5–2278.5 items/kg	PE, PP, PET	–	Fiber, film, granule, sphere, irregular	
Northern France	Landfill surroundings	Surface water: ~6 items/L Sediments: 50–1110 items/kg Mussels: 80–5830 items/kg	PP, PET	0.02–0.08 mm	Fragment, fiber, film, sphere	(Kazour et al., 2019)

(PE: polyethylene; PP: polypropylene; PEUR: polyether urethane; PS: polystyrene; EPM: expanded polystyrene; PUR: Polyurethane; PET: polyethylene terephthalate; PMMA: poly (methyl methacrylate); PVC: polyvinyl chloride; PA: polyamide; MSW: municipal solid waste; IW: industrial waste).

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Note: Microplastic information from landfill leachate from around the world from table 1 in "Solid waste: An overlooked source of microplastics to the environment (Golwala et al., 2021)."

Table 2.

Wastewater Sludge Microplastic Information

Location	Microplastics concentration	Microplastics composition	Microplastics size range	Microplastics shape	References
USA	0–12 g/kg	PET, PC	–	–	(Zhang et al., 2019)
	800–4000 items/kg	–	<5 mm	Fiber	(Carr et al., 2016; Zubris and Richards, 2005)
France	14,930–17,330 items/kg	PS, PE, PET, PP, PVC	0.02–0.5 mm	Fiber, fragment	(Kazour et al., 2019)
China	1565–271,700 items/kg	PA, PP, PE, polyolefin, acrylic	0.025–5 mm	Fiber, fragment	(Li et al., 2018b; Yang et al., 2019; Liu et al., 2019; Li et al., 2019; Lv et al., 2019)
Italy	56,000–170,000 items/kg	PES, PA	0.5–0.1 mm	Fiber, fragment	(Magni et al., 2019)
Poland	6700–62,600 items/kg	–	–	–	(Wisniowska et al., 2018)
Canada	Primary sludge: 8600–21,200 items/kg Secondary sludge: 1500–7300 items/kg	–	–	Fiber, fragment	(Gies et al., 2018)
Ireland	4196–15,385 items/kg	PA, PP, PET	0.25–4 mm	Fiber, fragment, film, sphere	(Mahon et al., 2017a)
Germany	1000–24,000 items/kg	PE	<5 mm	–	(Mintenig et al., 2017)
Mexico	18,000–41,000 items/kg	Acrylic, PES, nylon, LDPE, PVC	0.5–4.1 mm	Fiber, fragment	(Corradini et al., 2019)
UK	~2000 items/kg	–	1.34–1.62 mm	–	(Murphy et al., 2016)
Finland	8.2–301.4 items/kg	–	<1 mm	–	(Lares et al., 2018)

(PET: polyethylene-terephthalate; PC: polycarbonate; PS: polystyrene; PE: polyethylene; PP: polypropylene; PVC: polyvinyl chloride; PES: polyester; PA: polyamide; LDPE: low density polyethylene).

Note: Microplastic information from wastewater sludge from around the world from Table 3 in "Solid waste: An overlooked source of microplastics to the environment (Golwala et al., 2021)."

2.7. Microplastics Entering the Environment

With this wide range of plastics and microplastics present it raises the question of, "How are these microplastics entering the environment?" Most microplastic pollution comes from improper waste management (He et al., 2019). Microplastics can enter the environment through a variety of sources, but most are not just inherently dumping microplastics into the environment. Instead, the majority of microplastics can be credited to coming from two main sources: direct introduction via runoff and weathering of plastic litter (Andrady, 2011).

Direct introduction often comes from sources such as wastewater discharge, landfill leachate, or stormwater. While wastewater treatment plants do an excellent job at removing larger macroplastics, these plants struggle to remove the small microplastics (Cole et al., 2011). Microplastics are small enough, that they can seep past most filtration techniques and are strong enough to survive throughout the digestion processes in wastewater treatment. Microplastics can occur in wastewater or leachate either due to plastic fibers being removed from clothing during the washing process or macroplastics being weathered and carried into the water. Wastewater is water that is discharged from a wastewater treatment plant, which is where the wastewater from the community is collected and treated to be discharged back into the environment. Wastewater discharge has the potential to carry large amounts of microplastics that make their way through the wastewater treatment plant. The microplastics in wastewater are more likely to be either small beads from cosmetic facewashes or plastic fibers from clothes when they are washed. The microplastics that come from wastewater discharge are different than the microplastics created from littered plastic and are often less weathered and different in

shape. These conclusions were based on the information presented from the studied articles

For example, one of the main sources of microplastics were cosmetic microbeads that were used in facial cleansers. In the article, “The Influence of Cosmetic Microbeads on the Sorptive Behavior of Cadmium and Lead Within Intertidal Sediments: A Laboratory Study,” written by Boucher et al. in 2016, a research project pertaining to cosmetic microbeads was completed to show not only how these beads enter the wastewater system but also how they behave and interact with heavy metals. Since this study was completed, most cosmetic companies have ceased use of plastic microbeads in their cleansers, but that does not remove the beads already present in the environment.

There have been several other studies besides Boucher et al. that have concluded that plastics can enter the environment through cosmetic washes. Golwala et al. in 2021 also implied that microplastics end up in WWTPs due to personal care products and are retained in the sludge which can be distributed into the environment. There was additionally a study in 2019 conducted in the Changjiang River that found large amounts of fibers in the Changjiang River due to wastewater and cleanser beads and these microplastics are more apt to foul and sink (Zhao et al. 2019). For more information one could read these articles, but in conclusion these articles are excellent resources to explain how microplastics can enter the wastewater and be distributed out to the environment.

Another source of direct introduction is landfill leachate. Landfill leachate is the runoff that is produced from the trash deposited in landfills. Landfills are a major source of microplastics due to the plastics that are disposed of in the landfill and the fact that the

leachate produced by said landfills can transfer microplastics (Golwala et al., 2021). In landfills there is a standard amount of leachate that is supposed to seep from the landfill through a liner. This allows for the water that is deposited into landfills to slowly seep back into the environment. The treatment of leachate does not actually remove plastics it only controls the amount entering the environment and treatment (He et al., 2019).

He et al. in 2019 conducted a study on several different landfills to prove the leachate as a possible source of microplastic contaminants. They concluded that leachate from landfills can seep into the environment easily either through the controlled amount that is supposed to leave the landfill or through, "defects in geomembranes (landfill liner) (He et al., 2019, p. 42)." In landfills the plastic that is disposed of degrades causing microplastics to occur in the leachate (He et al., 2019).

Another issue about wastewater and landfill leachate is that no matter the precautions put in place these sources of microplastic pollution will be difficult to eradicate. Wastewater distribution is essential for a community to exist and landfill leachate still exists even if the landfill is closed. The study completed by He et al. in 2019 studied landfills that were open and closed, and still found that microplastics were being leached within the leachate. Since these sources are so essential and already installed it creates a difficult predicament to fully remove microplastic pollution due to these indirect sources. However, direct source pollution due to plastic littering could be prevented.

The main source of microplastics would be from the weathering of littered plastic. When large pieces of plastic are littered into the environment, they can be weathered to create microplastics. "Plastic litter with a terrestrial source contributes 80% of the plastics found in marine litter (Cole et al., 201, p. 2590)." Plastic littering can originate from a variety of

sources. Commonly land-based plastic pollution contributes to more pollution than marine-based pollution (Lebreton et al., 2017). Land-based pollution would consist of sources such as tourism on beaches, plastic production pellets, or trash (Cole et al., 2011). Marine- based pollution is frequently due to fishing supplies being lost or thrown into the ocean.

Plastics littered on beaches degrade into microplastics faster than plastics in the water due to the UV and heat weathering (Andrady, 2011). However, fishing gear that is lost in bodies of water could cause more harm than just microplastic pollution. Lost fishing gear could lead to ghost fishing, which is where the lost fishing gear continues to entangle fish. Sometimes pollution is related to the population in each area, but also tourism and climate have large influences on the pollution found in each area (Lebreton et al., 2017). Since plastic pollution contributes to such a high amount of the total pollution it would be best to create strategies to control the amount of plastic that is entering the environment through plastic littering (He et al., 2019).

2.8. Likeliness of Plastics to Adsorb

As microplastics enter the environment the microplastics are prone to adsorb metals and various other contaminants. Certain types of plastics tend to adsorb higher amounts of contaminants than others. Plastics abilities to adsorb contaminants differently could be due to their polymer make up (Bakir et al., 2014). In addition to the polymer composition affecting adsorption capacity, the weathering of the microplastics can also affect adsorption capacity.

2.9. Weathered Microplastics vs. Non-Weathered Microplastics

Weathering can be caused several different ways but the most common are by the sun and water. The UV rays from the sun tend to cause cracking and color change while microplastic particles are exposed to the sun. Weathering from sunlight is more apparent on microplastic particles that are found on beaches or riverbanks. The sun can still contribute to the weathering of microplastics in water, but only to microplastic particles on the surface of the water. The water itself can also cause weathering damage to the microplastics (Andrady, 2011). Certain plastics are also more prone to weathering than others. For example, plastics that have a high molecular weight are strong and therefore weathering will occur slowly. However biodegradable plastics have weaker molecular bonds, causing these plastics to weather at an exponential rate compared to the high molecular weight plastics (Andrady, 2011). Weathering is not the same as degradation, but for the purposes of this study the terms can be used interchangeably. There are five different forms of degradation: biodegradation, photodegradation, thermooxidative degradation, thermal degradation, and hydrolysis (Andrady, 2011).

As these forms of degradation occur, they weather the plastic particles increasing the surface area of each particle (Huang et al., 2020). The increase in surface area occurs when dents or scratches are formed on the surface of the plastic particle exposing more plastic to the environment. Once the plastic is exposed to the environment it is open to the adsorption of metals or additional contaminants. This increase in surface area is the main difference between weathered microplastics and non-weathered microplastics and is why weathered microplastics can adsorb higher amounts of contaminants. Studies that have examined this increase in adsorption include Holmes et al. (2020) and Huang et. al.

(2020). While these studies varied in the ways they were conducted both studies concluded that weathered microplastics adsorb higher quantities of metals than non-weathered plastics. Due to the fact that weathered microplastics can adsorb higher quantities of metals than non-weathered microplastics, weathered microplastics are a greater threat to the environment (Huang et al., 2020).

2.10. The Movement of Microplastics Through the Environment

A considerable amount of the weathering that occurs to microplastics occurs as the microplastics are transported throughout the environment. The majority of the transportation of microplastics occurs through bodies of water such as rivers, oceans, and lakes. Once microplastics enter these bodies of water the microplastics can be transported to areas that do not originally have microplastic pollution. Additionally, as these microplastics travel in these bodies of water further weather can occur and the microplastics can adsorb further contaminants.

As stated earlier there are several methods as to which microplastics enter the environment: wastewater discharge, landfill leachate, and plastic littering. However, entering the environment is not the final fate of microplastics, and they are often transported within bodies of water. Microplastics can travel vast distances withing bodies of water due to the fact that plastic is less dense than water (Teuten et al., 2007).

In addition to microplastics being directly introduced into bodies of water due to wastewater discharge, landfill leachate, and plastic littering, microplastics can also be washed into the bodies of water. Zhao et al. (2019) completed an experiment that showed that there tends to be higher amounts of microplastics in the water during the rainy

seasons due to the rain-washing plastics into the river. Additionally, more microplastics can be moved into water systems due to tsunamis. Tsunamis can sweep more plastics into a water system during the tsunami and can move large amounts of debris from one area to another (Lebreton et al., 2018).

2.10.1. Rivers

The primary water systems where microplastics occur are river, oceans, and lakes. Rivers are a massive source of microplastics being transported, since rivers actively move from one area into another. Rivers can deposit microplastics that are collected in land and then move them out to either oceans or lakes.

Rivers travel vast distances over which there are numerous opportunities for the rivers to acquire microplastics. These opportunities include wastewater discharge, landfill runoff, plastic littering, fishing, and numerous other sources. Additionally, the “high unidirectional flow” of rivers are suitable environments for microplastic transport (Cole et al., 2011).

Lebreton et al. (2017) when completing a modeling study estimated that around 1.15-2.41 million tons of plastic enter the world’s oceans from rivers yearly. Of the contributing rivers, the rivers exiting the continent of Asia contributed approximately 86% of the input of plastics (Lebreton et al., 2017). This continent includes the Changjiang River which is one of the largest in the world with high levels of microplastic pollution (Zhao et al. 2019). In addition to studies being done on the Changjiang River, Napper et al. (2020) completed a study on the Ganges River. In this river there were over 140 microplastic particles were found. Of the microplastics found in the Ganges River

91% were fibers and 9% were fragments (Napper et al., 2020). The large amount of fibers present could be due to the wastewater discharge that is contributed into this river, supporting the idea that rivers can carry microplastics from inland wastewater discharge out to oceans.

The amount of microplastics that enter the ocean from the various river systems around the world varies greatly depending on population. Areas of larger population trend towards distributing larger amounts of microplastics than smaller populations. For example, Asia, a continent with a massive population, was the leading continent for plastic pollution with approximately 86% of the world input for riverine microplastics according to a pollution model completed by Lebreton et al. (2017).

2.10.2. Oceans

When a river flows into the ocean the river can carry microplastics and other contaminants from inland areas and deposit these contaminants into the ocean. Additionally, like rivers, oceans are susceptible to microplastic pollution from plastic littering and wastewater discharge. Once microplastics enter the ocean the microplastics have the opportunity to travel vast distances.

Since the ocean is large there, it is exceedingly harder to quantify the amount of plastic present. The amount of plastic entering the ocean can be measured as apparent in the river study mentioned earlier. However, river input does not account for the number of plastics that enter through littering or fishing pollution. In order to quantify the amount of microplastics in the ocean there are several different methods including beach

combing, sediment sampling. Marine trawls, marine observational surveys, and biological sampling (Cole et al., 2011).

Many plastics become less buoyant over time and becoming deep sea sediments (Cole et al., 2011). There is importance in knowing the volume of microplastics in the ocean to understand the impact of microplastics in the ocean. Additionally knowing the volume of microplastics present in the ocean allows for one to better understand how these microplastics move throughout the environment.

One place that continuously collects microplastics within the ocean is the Great Pacific Garbage Patch. The Great Pacific Garbage Patch (GPGP) is an area between California and Hawaii were plastic gathers (Lebreton et al., 2018). The majority of the microplastics that are present in the GPGP occur from landfills or littering either from tourism or fishing and consists of polyethylene (PE) and polypropylene (PP) plastic (Lebreton et al., 2018). Since plastic collects in the GPGP it gives an excellent perspective to what plastics are present in the ocean and how they behave. For example, as stated earlier the continent of Asia contributes the largest amount of microplastics to rivers which is also evident in the ocean. Within the GPGP the estimated amount of microplastics would be 6.4 thousand tons largely originating from Japan and China. Lebreton et al (2018) conducted a study to determine the contents of the GPGP. Reference Lebreton et al. (2018) for a comprehensive explanation of this study. While the GPGP is harmful for the ocean it does help researchers understand the plastic make-up of the ocean.

2.10.3. Lakes

Unlike rivers and oceans, lakes normally stand alone, and do not have a source flowing into them. Lakes are also less susceptible to wastewater or leachate discharge. However, lakes are often used for several different recreational activities making lakes still susceptible to plastic littering. Additionally, even without input from a river or wastewater discharge some microplastics could be transported through the air, but this is less likely (Zhang et al., 2016).

In the article, "Microplastic pollution of lakeshore sediments from remote lakes in Tibet plateau, China," by Zhang et al. (2016) a study was completed analyzing the microplastics that are present in a remote set off lakes on the Tibet Plateau. The Tibet Plateau has little human traffic, so it is problematic that microplastic pollution still takes place in this area. There is not as much research concerning lakes as there is for oceans and rivers (Zhang et al., 2016).

> "Meanwhile, waters situated in remote areas usually face harsh environmental conditions and their aquatic ecosystems can be more vulnerable to pollution. Therefore, it is important to understand the characteristic of microplastic pollution in remote waters (Zhang et al., 2016, p. 451)."

The Zhang et al. experiment studied four different lakes on the Tibet Plateau and their shoreline sediments for microplastics. Reasons why these lakes and other lakes around the world have microplastic pollution could be due to improper waste management (Zhang et al., 2016). If a lake has human activity littering pollution would be present. Otherwise input from rivers could bring microplastic pollution from other areas into the

lake. For example, the Tibet Plateau lakes are near the estuary of Boques Zangbo, which has a large amount of microplastics that could be feeding into the lakes (Zhang et al., 2016). In the lakes in the Zhang et al. study the most common plastics found were PE, PP, PS, PET, and PVC (Zhang et al., 2016). These plastics may be more present due to the fact that they are lighter and can travel farther (Zhang et al., 2016).

2.11. Aquatic Environment Affects Movement

Whether the microplastics are in a river, ocean, or lake the aquatic environment affects how microplastics behave within the water. Understanding how these water systems behave can allow researchers to understand how microplastics travel and therefore how to reduce microplastic pollution. Since rivers are known to carry microplastics out to the ocean or lakes reducing microplastic pollution in rivers could greatly reduce microplastic pollution worldwide. The majority of microplastic pollution comes from the fishing and tourism industries, so discussion on how to reduce pollution in these industries would be beneficial.

Other than rivers, oceans, and lakes. microplastics can move through other forms such as land waste application. Land waste application occurs when fertilizer that is created in a wastewater treatment plant from processing the sludge. The fertilizer is then applied to the land for crop use. This process allows WWTPs to sustainably dispose of the sludge that is created in the treatment process. However, when this fertilizer is applied the microplastics that are not destroyed in the WWTP digesters can be transported to the soil.

The different types of water in each of the aforementioned bodies of water can also affect the microplastics. Seawater can cause larger amounts of weathering, which can cause microplastics to be able to adsorb larger amounts of heavy metals. Additionally, if the water that is carrying the microplastics is polluted then the microplastics will be able to adsorb said pollution.

2.12. Microplastics Appearing in Areas Without Direct Microplastic Pollution

After microplastics enter the environment, they can travel vast distances to areas that would not originally have microplastic pollution. It is easy to assume that areas with heavy human influence have microplastic pollution, however it is harder to understand how unpopulated areas of the world become polluted. For example, the Southern Ocean has increasing numbers of microplastic pollution and there is evidence of microplastic pollution in the Artic Sea ice (Waller et al., 2017). In a study completed by Waller et al. and published in, "Microplastics in the Antarctic Marine system: An emerging area of research," there has been a considerable amount of microplastic pollution found in the Southern Ocean and Antarctica. This is concerning due to the lack of human influence in these areas. There has been microplastics found in the deep sediments near Antarctica (Waller et al., 2017). Additionally, there has been microplastic amounts in certain studies equivalent to populated areas (Waller et al., 2017).

The presence of microplastics in these remote areas raises the question of how they got there. Microplastics may enter the environment from wastewater or microplastic degradation and then mix with deep ocean sediments to enter these far away areas (Waller et al., 2017). Microplastics may also be sourced from the wastewater discharged from research stations (Waller et al., 2017). Waller et al. found in their study:

> "Estimates of daily microplastic use per person in personal care products ranged between 2.4 and 27.5 mg day−1. We estimated a maximum potential input (i.e., based on 18.2 million person days per decade) of between c. 44–500 kg of microplastic particles entering the Southern Ocean per decade from personal care products (Waller et al., 2017, p. 224)."

Additionally, they found that 680- 1900 synthetic fibers are released in the wash (Waller et al. 2017). In the colder temperatures of the Southern Ocean slows degradation of these microplastics, however the high UV rates in the summer can cause degradation (Waller et al., 2017). It is difficult to control the plastic pollution in an area such as Antarctica due to the fact that there is not one government controlling Antarctica but instead a series of treaties (Waller et al., 2017).

2.13. Facilitated Transport of Pollutants

The way these pollutants are travelling to different regions is problematic due to the fact that microplastics can carry pollutants from one area to another. Microplastics, besides being harmful by themselves, can transport adsorbed pollutants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and per- and polyfluoroalkyl substances (PFAS) (Golwala et al., 2021). These pollutants are adsorbed to the microplastics when they pass through landfills or wastewater treatment plants where these pollutants are abundant (Golwala et al., 2021). Microplastics can also adsorb nutrients or pollutants when land applied through fertilizer from wastewater treatment plants (Golwala et al., 2021).

> "Microplastic debris coated with POPs may be transported across oceans polluting otherwise pristine ecosystems, or be ingested by marine organisms, thus transferring toxins from the environment to biota (i.e., a ‘‘Trojan horse’’ effect). Many POPs are considered toxic, inducing endocrine disruption, mutagenesis and/or carcinogenesis, and may biomagnify in higher-trophic organisms (Cole et al., 2011, p. 2595)."

Microplastics travel through water effortlessly due to them being less dense than the water. In conjunction with being transported throughout water systems, microplastics can sink and desorb contaminants into ocean sediments (Teuten et al., 2007).

Once microplastics adsorb pollutants and travel throughout the water they can enter the food chain of many organisms. These organisms can then be consumed by other sea life or humans (Golwala et al., 2021; Holmes et al., 2012; Teuten et al., 2007).

Once consumed by organisms the organisms the adsorbed contaminants on microplastics the contaminants can be leached into organisms.

2.14. Leaching of Pollutants

As stated earlier different pollutants can adhere to the surface of microplastics. One of the main reasons this occurs is due to the plastic's composition and generous surface area (Cole et al, 2011). This adsorption can also lead to the slow leaching of pollutants creating a toxic environment (Cole et al., 2011). According to Nakashima et al. plastics can:

> "be a transport vector of (i) chemicals absorbed on plastic debris surfaces from the sur-rounding seawater and (ii) additives originally incorporated in plastics (Nakashima et al., 2016, p. 333)."

These contaminants that are present can include POPs and polycyclic aromatic hydrocarbons as well as metals (Nakashima et al., 2016). Additive-derived metals that are involved in the formation of plastics can also leach from contaminants (Nakashima et al., 2016).

> "Examples are antimony trioxide commonly incorporated into polyethylene terephthalate, and stabilizers like lead stearate that enhance smoothness and stability of polyvinyl chloride (PVC) polymer (Nakashima et al., 2016, p. 333)."

> "For example, polyvinyl chloride (PVC), polycarbonate, polyurethane and polystyrene (PS) are composed of hazardous monomers (e.g., vinyl chloride, bisphenol-A and styrene) and/or contain hazardous additives (e.g., PBDEs, phthalates and lead) (Rochman, Hentschel, & Teh, 2014, p. 2)."

In addition to the make-up of plastics including harmful pollutants, plastics can also adsorb metals and organic pollutants. For example, Nakashima et al. found high levels of metals within plastic debris especially lead (Nakashima et al., 2016). These researchers found levels of lead as high as 13,500 ± 8400 mg/kg (Nakashima et al., 2016). Nakashima et al. concluded that plastic debris could leach lead at sporadic rates, which could lead to transport of metals long distances (Nakashima et al., 2016). Organic chemical pollutants can also adsorb to plastic debris (Rochman, Hentschel, & Teh, 2014). These pollutants can adsorb to microplastics through either the manufacturing process or by exposure in the environment (Rochman, Hentschel, & Teh, 2014). These chemicals can include polycyclic aromatic hydrocarbon (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides (OCPs) (Zhang et al., 2016). The pollutants that are adsorbed to plastics can be transported by plastics to various locations and then leached

into the environment. This can occur through desorption which will be discussed in a later section.

2.15. The Health Effects to Organisms

With the small size and shape of microplastics, they can be mistake for food and be consumed by organisms (Bakir et al., 2016; Cole et al., 2011). Once microplastics are consumed by organisms the microplastics can become toxic via adsorbed chemicals or bioaccumulation (Bakir et al., 2016; Cole et al., 2011). The metals or organic chemical pollutants that adsorb to microplastics can become bioavailable when the microplastics are consumed (Rochman, Hentschel, & Teh, 2014; Andrady, 2011; Cole et al., 2011). This exposure to metals and organic pollutants could be toxic to organisms and cause decreased growth or carcinogenic behavior (Rochman, Hentschel, & Teh, 2014; Golwala et al., 2021). In addition to leaching harmful contaminants microplastics can be harmful due to their size and shape. Microplastics can bioaccumulate within cells and cause inflammation and disrupt important bodily functions (Golwala et al., 2021). Pico- and nanoparticles can even enter cells and desorb contaminants or cause damage (Andrady, 2011). Systems commonly affected by microplastics include the reproductive and nervous systems (Golwala et al., 2021).

Microplastics can affect a multitude of organisms including invertebrates, fish, mammals, and humans. Lower-level organisms such as bacteria, invertebrates, and filter feeders feed on microplastics due to the fact that they cannot tell the difference between microplastics and food (Andrady, 2011; Wei et al., 2021; Bakir et al., 2016; Cole et al., 2011). Microplastics do not have as much of an effect on lower-level organism. as it does to the organisms who consume them (Andrady, 2011). The microplastics can

bioaccumulate and then transfer through lower-level organism to higher-level organisms (Andrady, 2011).

One of the higher-level organisms that can be affected are fish. The plastics that were ingested by fish were mainly found to be harmful due to the chemicals present within the microplastics. Rochman et al. completed two different studies in 2013 and 2014 concerning microplastic ingestion in fish. Microplastics can cause several adverse health effects including hepatic stress, liver lesions, endocrine disruption, pre-tumors, and reproductive issues in female fish (Rochman et al., 2013; Rochman et al., 2014). Death was not exhibited within these studies, but the harmful side effects could lead to death (Rochman et al., 2013; Rochman et al. 2014).

Mammals are also subject to microplastic ingestion. Marine mammals, seabirds, and sea turtles are a few of the mammals that have been shown to ingest plastic (Rochman, Hentschel, & Teh, 2014; Cole et al., 2011). It has been found that there is lesser impact of microplastics on these larger organisms (Bakir et al., 2016). This fact could be due to the chain of feeding and elimination by lower-level organisms (Bakir et al., 2016). However, there is still a similar impact of being exposed to metals and chemicals from the ingested microplastics (Rochman, Hentschel, & Teh, 2014).

Fish and mammals that are used for food can enter the human food chain.

> "Studies have found up to 15 microplastics per fish, 3.7 microplastics per mussel, and 7 microplastics per oyster (Golwala et al., 2021, p. 4)."

The microplastics ingested by humans can cause a multitude of health effects. These can be due to the bioaccumulation of microplastics or the contaminants they carry (Golwala

et al., 2021). The health effects present for humans include: nerve and reproductive system stress, carcinogenic behavior, and lung and liver damage (Golwala et al., 2021).

2.16. Effects to Metal Adsorption

Metals adsorb to plastic surfaces due to the anatomy of the metals and plastic surface. The adsorption often occurs via the bivalent cations present within metal ions and the polar surfaces of plastics (Zou et al., 2020; Holmes et al., 2012).

> "We proposed that metal adsorption proceeds through electrostatic interactions between bivalent cations (e.g., Cu2+, Cd2+, Pb2+) and the charged or polar regions of the plastic surface or via surface complexation onto the plastic surface (Zou et al., 2020, p. 10)."

> "Presumably, metal adsorption proceeds through interactions between bivalent cations (e.g. Cu2+, Cd2+, Pb2+) and oxyanions (e.g. Cr2O24) with charged or polar regions of the plastic surface (effected by imperfections and the presence of charged contaminants and additives, for example), and via non-specific interactions between neutral metal-organic complexes and the hydrophobic surface of the bulk plastic medium (Holmes et al., 2012, p. 47)."

Other factors may also affect metal adsorption including hydrated ionic radius, ionic strength, pH, and length of time exposed to plastics. The hydraulic radius affects the electrostatic interactions. Zou et al. found that the smaller the hydraulic radius the larger the electrostatic interactions (Zou et al., 2020). High ionic strength can decrease adsorption through:

> "(1) the increasing competition of cation with increased ionic strength for the sorption sites of sorbents, (2) decreasing activity of ionic chemicals in solution, and (3) compression of the electrical double layer (Zou et al., 2020, p. 10)."

pH of the water can also contribute to adsorption affinity of metals (Holmes et al., 2014; Zou et al., 2020). Higher pH can increase adsorption through two different ways:

> "First, when the pH decreased, H+ can compete with the metals for the adsorption sites of MPs, thereby leading to a low metal adsorption capacity. Second, with increased pH of the solution, the functional groups of the surface of MPs were deprotonated, which should increase the electronegativity and sorption sites of the MP surface (Zou et al., 2020, p. 8)."

However, the metal and water characteristics may not be as important as the amount of time that the plastic is exposed to the metal in the water. The longer metals are exposed to plastics the more they will adsorb to a plastic and reach equilibrium (Rochman, Hentschel, & Teh, 2014). Equilibrium is when the plastic has adsorbed the highest number of metals physically possible by the plastic. Additionally, as plastics remain in the water longer they can form biofilms, which can adsorb higher amounts of metals (Rochman, Hentschel, & Teh, 2014). Additionally, weathered microplastics have a larger surface area for adsorption than new microplastics.

In order to observe how these differences in adsorption present themselves in case studies the following graphs and tables have been included in this literature review. Table 3 was adopted from the Holmes et al. study competed in 2012. Please see this article for more details on the study, but Table 3 shows what trace metals adsorb to plastics in

several bays in England (Holmes et al., 2012). This table is helpful to understand what metals are present in the environment and how their adsorption compares to one another.

During the study completed for, “Adsorption of three bivalent metals by four chemical distinct microplastics,” by Zou et al. in 2020 the adsorption capacities of metals to different types of plastics and the effect of pH and ionic strength to the adsorption of these metals. Figure 5 was adopted from Zou et al., 2012 compares the adsorption isotherms of Pb2+, Cu2+, and Cd2+ to CPE, PVC, LPE, and HPE.

Figure 6 is adopted from the same Zou et al. study. However, Figure 6 shows the effect pH has on adsorption. Interestingly adsorption increases with pH. However, the research that was completed using the geochemical model that will be explained in later sections shows that adsorption is not affected by pH. The reason pH is observed to change in Figure 6 may be due to the different species that occur at higher pH.

Lastly, Table 4 is adopted from table 4 in the Zou et al., 2020 study. Table 4 gives the adsorption k values for the Freundlich model that was used in this study. These k values were late used in the modeling study completed for this study in order to model lead’s adsorption.

Table 3.

Trace Metal Amounts

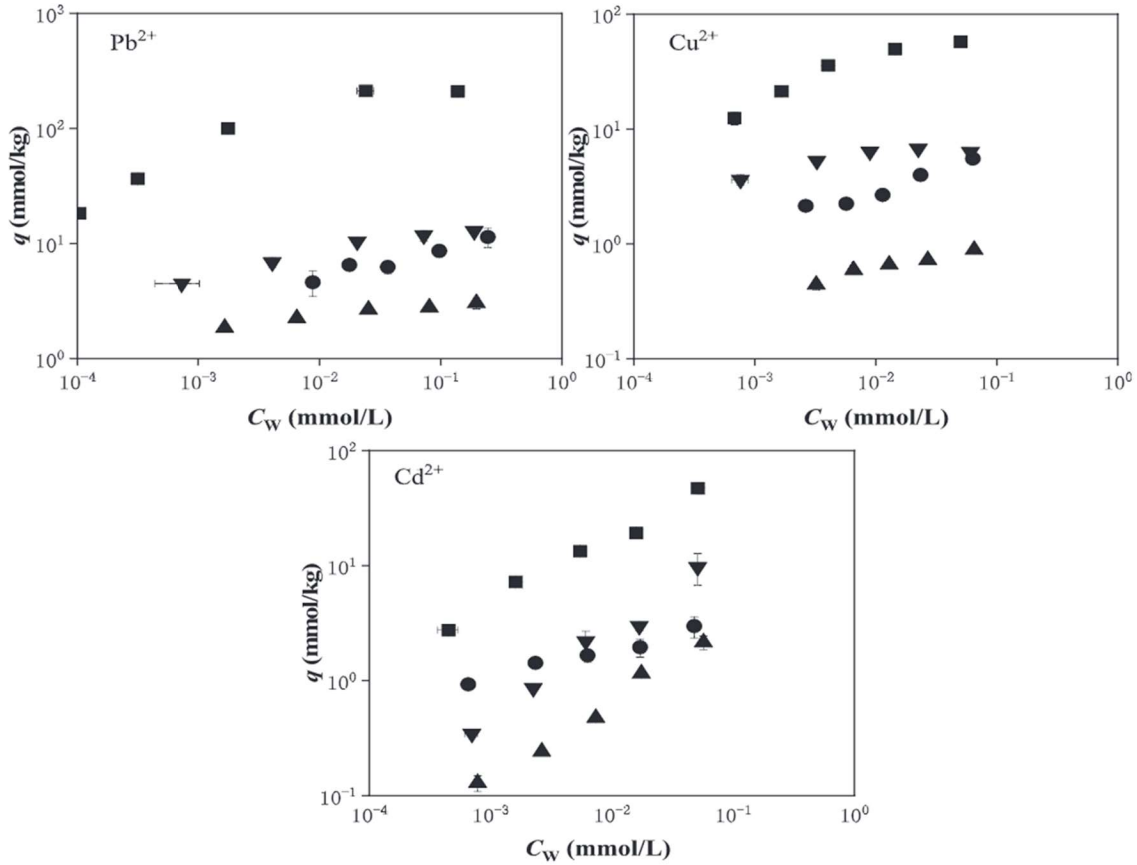
	Al μg g^{-1}	Fe μg g^{-1}	Mn μg g^{-1}	Cu μg g^{-1}	Zn μg g^{-1}	Pb μg g^{-1}	Cr ng g^{-1}	Co ng g^{-1}	Ni ng g^{-1}	Cd ng g^{-1}
Saltram										
Mean	55.8	97.8	20.5	0.441	2.68	1.02	237	107	131	1.65
SD	42.7	79.1	56.8	0.470	2.40	1.24	159	177	117	1.19
Median	41.0	67.5	5.01	0.283	1.63	0.544	212	44.9	91.1	1.17
Minimum	8.33	11.7	0.35	0.012	0.051	0.052	nd	nd	14.9	0.208
Maximum	171	314	308	2.38	10.0	5.85	821	787	562	4.33
Ninney Rock										
Mean	22.3	41.9	1.51	1.11	21.0	1.34	751	17.7	69.8	76.7
SD	15.7	30.5	2.68	1.90	58.5	2.39	142	15.8	40.5	134
Median	20.8	38.3	0.760	0.265	0.818	0.269	413	14.7	62.8	14.9
Minimum	nd	6.21	0.075	nd	nd	0.0232	nd	nd	nd	nd
Maximum	64.8	124.6	14.4	7.73	288	10.3	7970	71.8	157	492
Sharrow Point										
Mean	23.0	64.6	1.51	1.32	23.3	1.64	430	20.7	95.1	74.4
SD	18.2	38.9	2.39	1.80	56.7	2.40	210	19.8	59.3	143
Median	18.4	55.8	0.669	0.652	1.99	0.74	408	13.9	81.3	9.61
Minimum	3.77	nd	0.193	nd	0.065	0.016	nd	4.43	15.5	nd
Maximum	71.8	159	13.0	5.76	207	8.82	935	103	242	493
Watergate Bay										
Mean	16.9	48.5	1.16	0.064	0.299	0.149	44.0	22.5	40.0	1.09
SD	18.4	48.2	1.62	0.0618	0.292	0.181	39.5	47.7	40.4	1.39
Median	7.43	34.4	0.712	0.047	0.196	0.109	42.5	13.8	29.3	0.523
Minimum	nd	nd	0.079	nd	nd	nd	nd	nd	nd	nd
Maximum	81.8	239	8.66	0.239	1.04	0.885	88.0	262	164	5.36

SD: standard deviation; nd: not detected.

Note: Trace metal adsorption amounts from different location in south west England as adopted from table 1 in Holmes et al., 2012.

Figure 5.

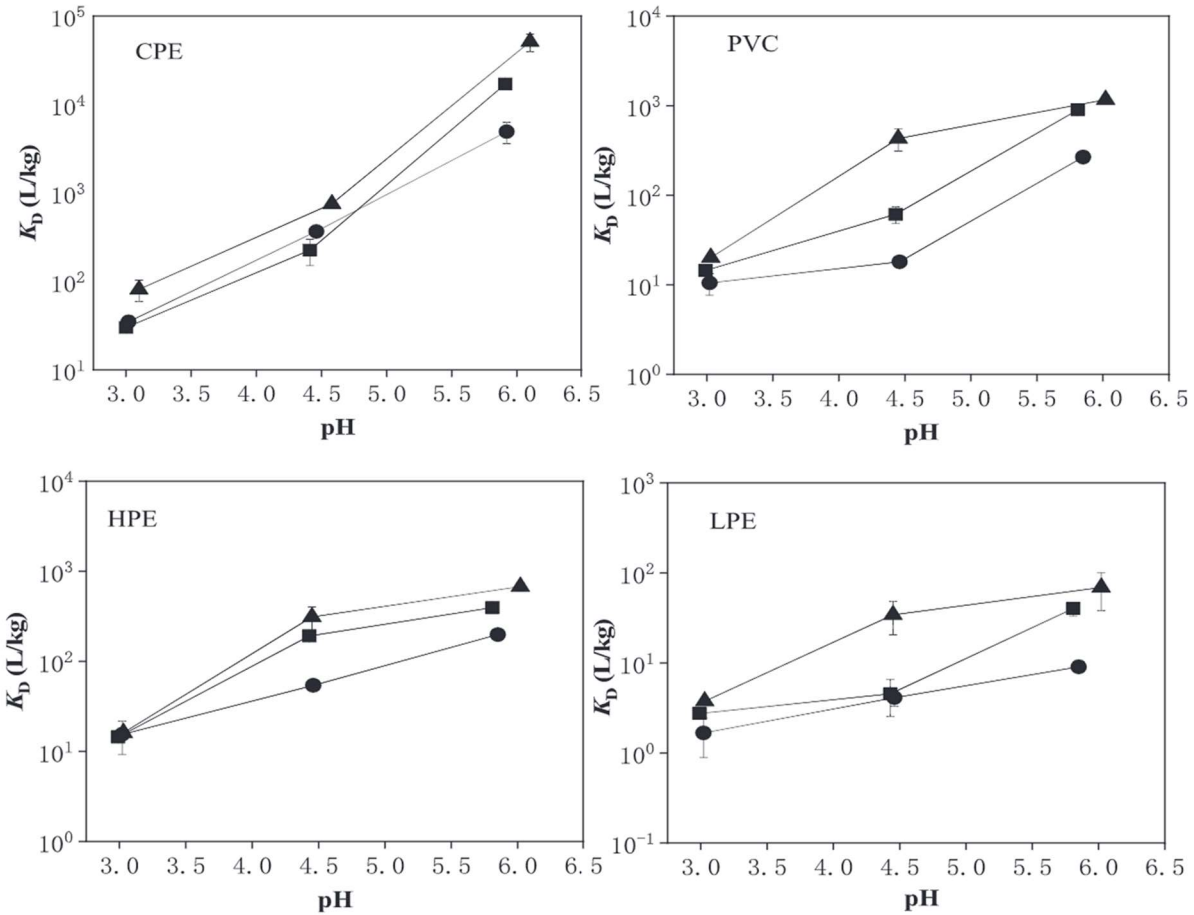
Comparison of Adsorption of Metal to Plastic



Note: A comparison of the adsorption ispotherms of lead (Pb2+), Copper (Cu2+), Cadmium (Cd2+) to Chlorinated Polyethylene (CPE), Polyvinyl Chloride (PVC), Low Crystallinity Polyethylene (LPE) and High Crystallinity Polyethylene (HPE). CPE=squares, PVC= downward triangles, LPE= upward triangles, and HPE=circles. As adopted from Figure 5 in Zou et al., 2020.

Figure 6.

Comparison of Adsorption Affected by pH



Note: A comparison of the adsorption of lead (Pb2+), Copper (Cu2+), Cadmium (Cd2+) to Chlorinated Polyethylene (CPE), Polyvinyl Chloride (PVC), Low Crystallinity Polyethylene (LPE) and High Crystallinity Polyethylene (HPE) at different pH values. Lead= triangles, Copper= squares, and Cadmium= Circles. As adopted from figure 6 Zou et al., 2020.

Table 4.

Freundlich Coefficients

Sorbent	Sorbate	K_F mmol^{1-n}L^n/kg	K_D[a] (L/kg)	n	R^2
CPE	Cu^{2+}	140 ± 22	8938	0.27 ± 0.04	0.900
	Cd^{2+}	227 ± 31	3060	0.56 ± 0.03	0.981
	Pb^{2+}	369 ± 59	71,908	0.22 ± 0.04	0.854
PVC	Cu^{2+}	13.4 ± 1.5	1508	0.17 ± 0.02	0.921
	Cd^{2+}	55 ± 11	322	0.68 ± 0.05	0.968
	Pb^{2+}	17.8 ± 1.2	1841	0.17 ± 0.02	0.921
HPE	Cu^{2+}	14.4 ± 1.6	340	0.35 ± 0.03	0.950
	Cd^{2+}	6.4 ± 1.1	493	0.26 ± 0.04	0.858
	Pb^{2+}	18.3 ± 2.2	240	0.29 ± 0.04	0.868
LPE	Cu^{2+}	1.55 ± 0.11	64	0.20 ± 0.02	0.948
	Cd^{2+}	14 ± 2.6	85	0.65 ± 0.06	0.971
	Pb^{2+}	3.5 ± 0.15	324	0.10 ± 0.01	0.900

[a] K_D was averaged from the K_D values obtained at different initial metal concentrations.

Note: The Freundlich coefficients found in the Zou et al., 2020 study for lead (Pb2+), Copper (Cu2+), Cadmium (Cd2+) to Chlorinated Polyethylene (CPE), Polyvinyl Chloride (PVC), Low Crystallinity Polyethylene (LPE) and High Crystallinity Polyethylene (HPE). As adopted from table 4 from Zou et al., 2020.

2.17. Properties of Each Metal

Table 5 shows characteristics for the metals that have been used in the studies discussed in this literature review and used in the following study.

Table 5.

Atomic Information of Metals

Atomic Information of Metals						
Metal:	Abbreviation:	Metal Type:	Atomic Weight:	Electronegativity:	Electron Affinity:	Energy Levels:
Chromium	Cr	Transition	51.996	1.66	64.3	2, 8, 13, 1
Cobalt	Co	Transition	58.933	1.88	63.7	2, 8, 15, 2
Nickel	Ni	Transition	58.693	1.91	112	2, 8, 16, 2
Copper	Cu	Transition	63.546	1.9	118.4	2, 8, 18, 1
Zinc	Zn	Transition	65.38	1.65	0	2, 8, 18, 2
Lead	Pb	Post- Transition	207.2	2.33	35.1	2,8,18,32,18,4
Aluminium	Al	Post- Transition	26.982	1.61	42.5	2,8,3
Iron	Fe	Transition	55.845	1.83	15.7	2, 8, 14, 2
Manganese	Mn	Transition	54.938	1.55	0	2, 8, 13, 2
Silver	Ag	Transition	107.87	1.93	125.6	2, 8, 18, 18, 1
Cadmium	Cd	Transition	112.41	1.69	0	2, 8, 18, 18, 2
Molybdenum	Mo	Transition	95.95	2.16	71.9	2, 8, 18, 13, 1
Antimony	Sb	Metalloids	121.76	2.05	103.2	2, 8, 18, 18, 5
Tin	Sn	Post- Transition	118.71	1.96	107.3	2, 8, 18, 18, 4
Uranium	U	Actinoids	238.03	1.38	N/A	2, 8, 18, 32, 21, 9, 2

Note: The essential properties of several metals.

2.18. Origin of Metal Pollution

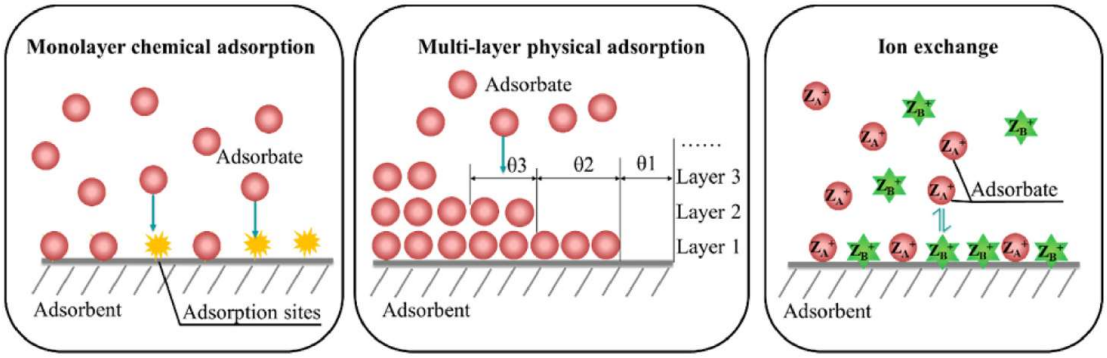
The metal pollution that causes metals to adsorb to plastics can originate from a variety of sources. One of the largest sources of metal pollution is paint particles particularly antifouling paints (Huang et al., 2020; Takahashi et al., 2012). These paint particles are usually created when maintenance takes place on older boats and ships (Takahashi et al., 2012). These particles can contain a variety of pollutants including metals: Cr, Pb, Zn, Cu, Al, and Sn (Takahashi et al., 2012).

2.19. The Mechanics of Adsorption

These metals and other contaminants adhere to microplastic particles through a process called adsorption. Adsorption occurs when adsorbates attach to adsorbents through Vander Waals forces or ion exchange (Wang & Guo, 2020). Figure 7 shows and visual representation of adsorption to better understand this process (Wang & Guo, 2020). Figure 7 was adopted from figure 1 in Wang & Guo, 2020. This figure shows how not only ion exchange happens but also chemical and physical adsorption.

Figure 7.

Visual Adsorption Model



Note: Visual representation of adsorption. As adopted from figure 1 in Wang & Guo, 2020.

As microplastics weather they gain surface area and can also acquire a bio film. These processes further create a larger surface area for these adsorption processes to occur (Cole et al., 2011; Holmes et al., 2012). The adsorption of contaminants to microplastics can be studied through isotherms (Wang &Guo, 2020).

2.20. Adsorption Isotherms

Adsorptions Isotherm models are used to describe the adsorption capacity of adsorbents (Wang & Guo, 2020). An isotherm is:

> "the relationship between the equilibrium adsorbate concentrations in the liquid-phase and the equilibrium adsorption amount on the solid-phase at a certain temperature (Wang & Guo, 2020, p. 3)."

Table 6 shows and compares several different adsorption isotherm models for a better understanding of what the different adsorption isotherms are capable of accomplishing. The adsorption isotherms in Table 6 are divided into three different categories:

Adsorption Empirical Isotherms, Chemical Adsorption Models, Physical Adsorption Models. The adsorption empirical isotherms do not have a definite physical categorization.

> "The chemical adsorption isotherm models consider the mono-layer adsorption process that the adsorbate molecules are adsorbed in the adsorption sites of the adsorbents. (Wang & Guo, 2020, p. 5)."

Physical adsorption models are guided by Vander Waals forces and replicate multilayer adsorption processes (Wang & Guo, 2020).

Table 6.

Adsorption Isotherm Models

Isotherm Model:	Model Category:	Description:	Frequency of Use:
Linear Method	Adsorption Empirical Isotherms	• Partition model between solid and liquid phase	Moderate
Freundlich Isotherm	Adsorption Empirical Isotherms	• Shows non-linear adsorption • Uses nonlinear regression analysis	High
Redlich-Peterson (R-P) Isotherm	Adsorption Empirical Isotherms	• Combination of the Langmuir and Freundlich models • Used for homogeneous and heterogeneous systems	Moderate
Sips Isotherm Model	Adsorption Empirical Isotherms	• Combination model • best for a 3-parameter isotherm experiment • monolayer adsorption	Moderate
Temkin Isotherm	Adsorption Empirical Isotherms	• Assumes adsorption is a multilayer process • Extremes are ignored	Moderate
Langmuir Model	Chemical Adsorption Models	• Shows gas-solid adsorption	High
Volmer Isotherm Model	Chemical Adsorption Models	• Assumes adsorption occurs on one layer and molecules can move throughout the layer	Low
BET Model	Physical Adsorption Models	• Used for the adsorption of gasses • Shows multilayer adsorption	Low
Aranovich Model	Physical Adsorption Models	• Uses poly-molecular adsorption capabilities • Used for more expansive concentration capabilities	Low

Note: This table describes the differences between several adsorption isotherm models as adapted from Wang & Guo, 2020.

2.21. Desorption

After adsorption occurs the contaminants that have been adsorbed to plastic can be desorbed from the plastic surface. There have been less studies completed on the desorption of contaminants than the adsorption of contaminants. However, there is some valuable information that has been gathered from the studies that have been complete. Studies have found that desorption occurs later, which can lead plastics to distribute

pollution (Nakashima et al., 2016). Since plastics do not desorb contaminants right after adsorption, the plastics can carry the pollutants long distances or be eaten by animals.

Desorption rates are greater when exposed to gut surfactants in organisms (Bakir et al., 2016; Bakir et al., 2014). This is concerning due to the fact that metals and organic pollutants can then be released inside the organism. The desorption due to gut surfactants could be up to 30 times greater than if just in seawater (Bakir et al., 2014). Table 7 shows the desorption rates discovered by this study to give an example of how fast desorption can occur (Bakir et al., 2014). Table 7 also compares simulated gut conditions (15 mM sodium taurocholate) and seawater (Bakir et al., 2014). One can observe that the desorption rates are higher under gut conditions than seawater.

Table 7.

Desorption Rates

Plastic	Pollutant	Aqueous phase: [(a)]Seawater at 18°C, pH 7.5-8.4 [(b)]Surfactant at 18°C, pH 7.5-8.4 [(c)]Surfactant at 38°C, pH 4	First order rate constant k (day^{-1})	Surfactant rate enhancement (seawater-surfactant)	pH and temperature enhancement rate
PVC	Phe	[(a)]Seawater	0.88 ± 0.33		
		[(b)]15 mM sodium taurocholate	1.67 ± 0.098	1.9	2.9
		[(c)]15 mM sodium taurocholate	4.8 ± 0.029	5.5	
PE		[(a)]Seawater	1.37 ± 0.26		
		[(b)]15 mM sodium taurocholate	3 ± 0.87	2.2	4
		[(c)]15 mM sodium taurocholate	12.10 ± 2.09	8.8	
PVC	DDT	[(a)]Seawater	0.26 ± 0.06		
		[(b)]15 mM sodium taurocholate	0.31 ± 0.07	1.2	1.7
		[(c)]15 mM sodium taurocholate	0.54 ± 0.2	2.1	
PE		[(a)]Seawater	0.23 ± 0.08		
		[(b)]15 mM sodium taurocholate	1.68 ± 0.38	7.3	4.3
		[(c)]15 mM sodium taurocholate	7.2 ± 0.9	31.3	
PVC	DEHP	[(a)]Seawater	na		
		[(b)]15 mM sodium taurocholate	1.37 ± 0.05		3.5
		[(c)]15 mM sodium taurocholate	4.86 ± 1.8		
PE		[(a)]Seawater	na		
		[(b)]15 mM sodium taurocholate	0.27 ± 0.1		14
		[(c)]15 mM sodium taurocholate	3.89 ± 0.22		

na: desorption rate not measurable over 3 hours.

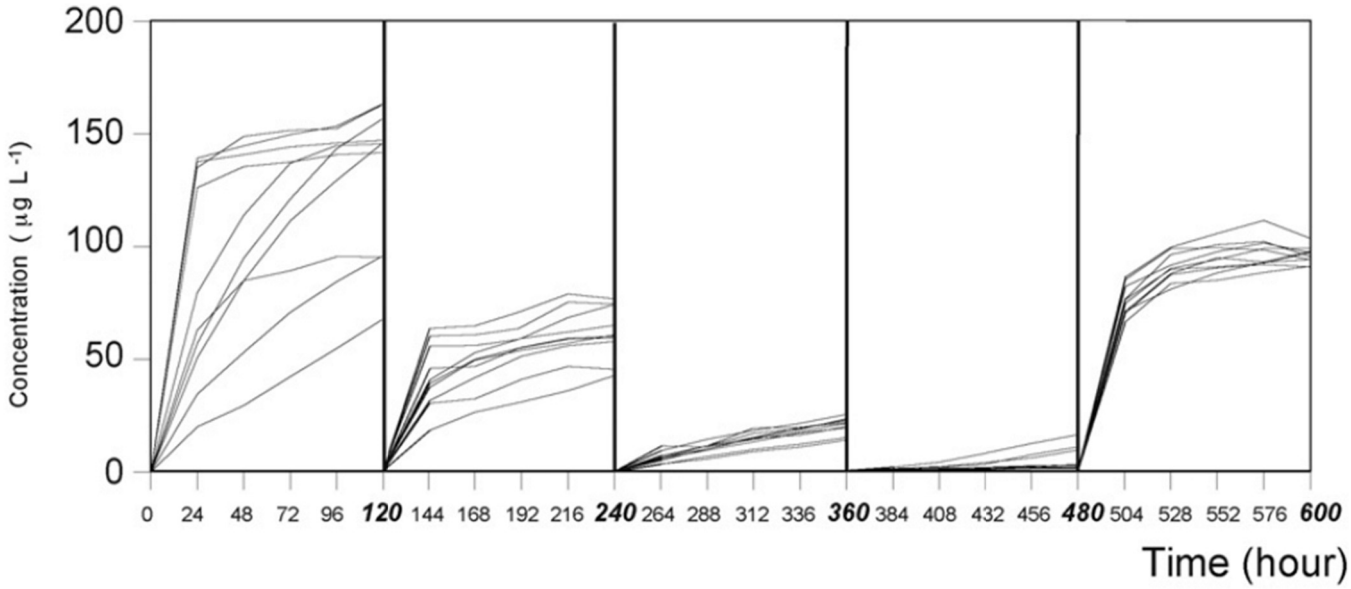
Note: Desorption rates of Phe (Phenanthrene), DDT (Dichlorodiphenyltrichloroethane), and DEHP (bis-2-ethylhexyl phthalate) to PVC and PE. Comparing simulated gut conditions (15 mM sodium taurocholate) to seawater. As adopted from table 3 in Bakir et al., 2014.

Additionally, as discussed earlier Nakashima et al. (2016) discovered that a "low Pb layer" could result in plastics ability to desorb lead slowly (Nakashima et al., 2016). Please see Nakashima et al.'s 2016 article for more information on this "low Pb layer."

Figure 8 shows an example of what slow desorption would look like (Nakashima et al., 2016). This figure allows one to better understand how desorption can occur through water systems, and how pollutants can be carried vast distances.

Figure 8.

Lead Leaching Curves



Note: Curves indicating the leaching of lead from PVC in water over time. As adopted from figure 2 in Nakashima et al., 2016.

2.22. Literature Review Conclusions

Microplastics are an emerging concern in today's world. Microplastic are not only harmful due to their size but also their ability to collect harmful contaminants including heavy metals. The harmful repercussions of this include consumption of microplastics by organisms and the desorption of contaminants spreading pollution. Microplastics enter the environment through a variety of ways including wastewater treatment plants, landfill leachate, and littering. Once they enter the environment microplastics can be distributed throughout rivers, the ocean, and lakes.

After reviewing the large volume of literature that created this literature review it was decided to do a geochemical modeling study to better understand the effect that a plastic adsorption surface can have on the heavy metals that travel through a wastewater treatment plant. Sections 3-6 explain this study.

3. MATERIALS AND METHODS

To better understand adsorption with microplastics in WWTPs a geochemical modeling study was conducted using Visual Minteq. In order to complete this modeling, wastewater samples needed to be collected from a local wastewater treatment plant and ran through several lab tests in order to create a background wastewater condition. Then the wastewater constituents were inputted into Visual Minteq to observe and better understand the adsorption of lead to plastic in these conditions. This adsorption was completed for the wastewater from the influent, clarifiers, digesters, and effluent.

3.1. Collection of Samples

To create the adsorption model that was used in this study the water characteristics throughout a wastewater treatment plant were needed. To obtain the needed water characteristics samples were collected from several locations within a local wastewater treatment plant. Wastewater samples were collected from the influent water, primary clarifiers 1 and 2, digesters 1 and 2, and the effluent water. All the samples that were collected were grab samples. The influent sample was collected from the influent manhole. The clarifier samples were collected from each clarifier. The digester samples were collected using a sampling method from the digester pumps. The effluent sample was collected from the effluent manhole. Additionally, 4 field blanks were collected for quality control. Field blanks were created using nanopure water which was poured into sample containers at each location to simulate collecting the samples in each location. Field blanks we collected at the influent manhole, the clarifiers, digester pumps, and effluent manhole. There was only one field blank collected for the clarifier and digester

samples because they were collected in the same area, so the ambient pollution should be the same.

3.2. Lab Tests Completed

Lab tests were completed using the Water and Environmental Engineering Research Center (WEERC) lab. The ammonia test was completed using standard method 4500-NH3D. The slope for the ammonia test used 0.1, 1, and 10 ammonia standards to establish a slope. Then for quality control a check of 7.5 was diluted 50%, a 40 ammonia standard was used, and a wastewater quality control sample was used. The 7.5 check was used to check the ammonia standard curve to check for bias or a curve. The wastewater control was an outside source check. The results for this check should be within 80% of what the source lab reported.

The electroconductivity test was completed using standard method 2510B. Nanopure water and a check standard with an electroconductivity of 792 were used for quality control for this test. The nanopure water was used to prove that the nanopure water has low conductivity. The check is to check that it is reading the samples correctly by matching to an outside source.

The Biological Oxygen Demand (BOD) was completed standard method 5210B. Two blank samples were used for quality control and were treated just like the samples to check for any glass or other contamination. Additionally, any probe contamination would be accounted for from using check samples. The BOD test that was completed was a 5 day BOD test. However, from this point on BOD will be referred to at BOD instead of BOD_5.

The Ion Chromatography (IC) samples were prepared and tested using EPA standard method 200.7. For quality control there are two checks. A catalogue 739 check is and a 275 (check paper) check were used. These checks are from a pt analyzation and evaluate all the metals the IC tests for. These checks were prepared from an outside lab and check lab proficiency.

The pH of each sample was acquired using standard method 4500-H+. Digester 2 was not studied for this portion due to lack of sample so the pH of digester 1 was used for the digester calculations. The pH probe is calibrated using three pH standards that are prepared from an outside source that are known to have pH's of 4,7, and 10.

The alkalinity test was completed using standard method 2320-B. For quality control on the alkalinity test a HACH wastewater QC sample was used to check the test results against an outside source.

3.3. Visual Minteq Input Compilation

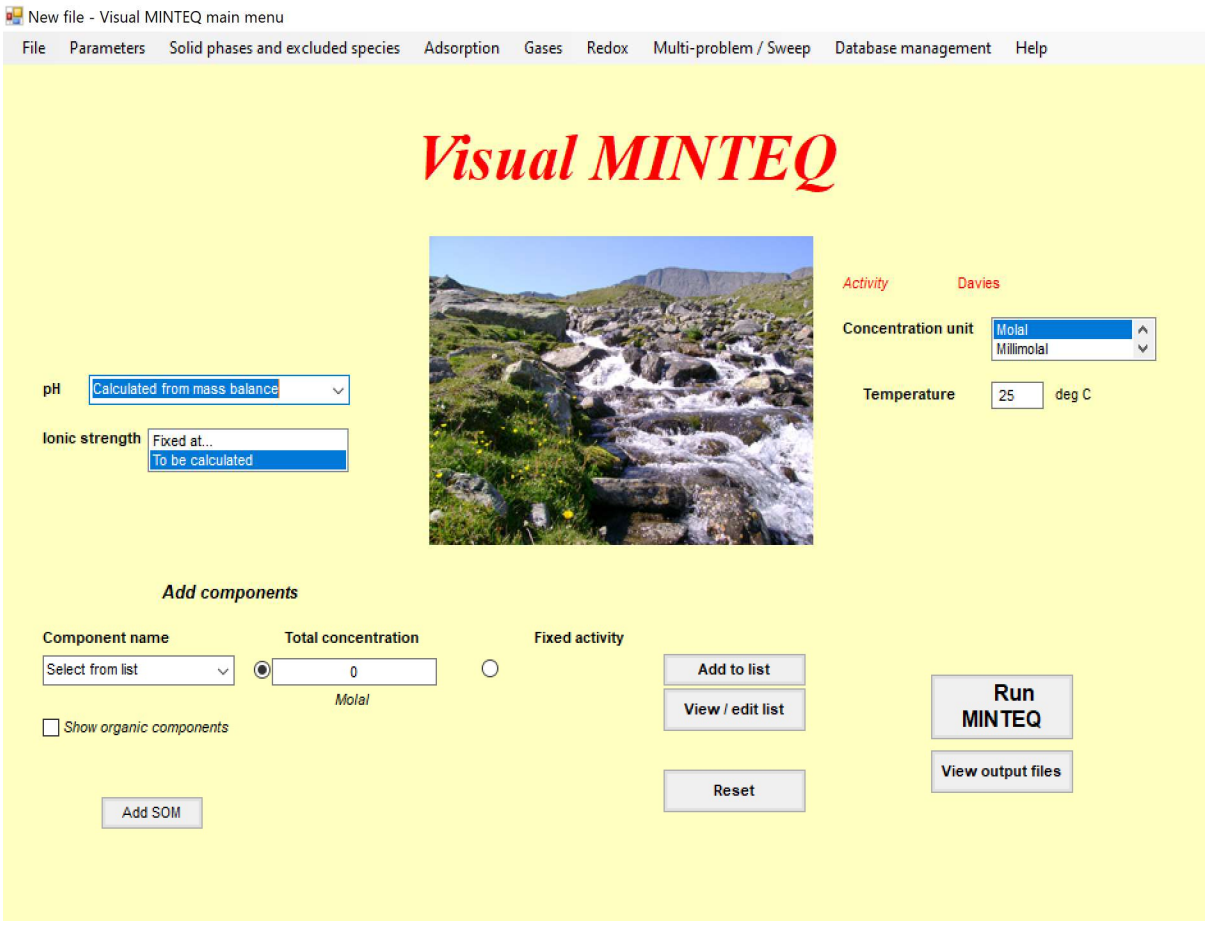
Table 27 contains the concentrations for different cations that are present in water (Qasim, Motley, & Zhu, 2000). The surface water values were used for cation concentrations in Visual Minteq due to the fact that surface water would have the closest physical properties to municipal wastewater. This was an approximation due to not having the ability to test for these cations but wanting to see their impact on adsorption.

The values from Tables 8-12 and Table 27 were used to calibrate the Visual Mintequ adsorption model that was used to study the adsorption of lead to PVC for the remainder of the study. Visual Minteq is a software program that shows the amount of adsorption that occurs when a variety of water parameters are imputed. An image of

Visual Minteq can be seen in Figure 9. The parameters that were imputed included: ammonium, ionic strength, Dissolved Organic Carbon (DOC), fluoride, chloride, bromide, nitrite, nitrate, sulfate, phosphate, pH, calcium, magnesium, sodium, potassium, and iron. The calculations for ammonium and ionic strength can be seen Appendix A. Additionally, the input values for each section of the wastewater treatment plant can be found in Appendix B.

Figure 9.

Visual Minteq Home Screen



Note: An image of the Visual Minteq home screen.

Once the input values were found for Visual Minteq the adsorption runs could be completed. Several adsorption runs were completed for each location including with DOC, with DOC & lead, with DOC, lead, & plastic adsorption surface, with lead & plastic adsorption surface, and with lead only. Ten milligrams of lead was chosen to study to the effect of heavy metals in the studied wastewater conditions. Ten milligrams of lead was chosen as the amount to use to have a large enough amount of lead available to see changes in the study. DOC was studied separately from the plastic surfaces due to its known adsorption properties to see its effect on the plastic adsorption surface. PVC was chosen as the plastic used to model the plastic adsorption surface. A k value was needed to calculate the adsorption of lead to PVC. The k value was found through research of existing adsorption studies and was found to be 17.8 mmol*L H_2O/kg plastic from Zou et al.'s 2020 study, "Adsorption of three bivalent metals by four chemical distinct microplastics." This k value was defined as a Freundlich isotherm k value in this study. A one-to-one stoichiometry relationship was assumed for this adsorption due to that being the suggested relationship for Visual Minteq. The L/S ratio is the liquid to solid ratio that exists in the wastewater being tested. L/S ratios were calculated separately for each area. The calculations for L/S ratio are located in Appendix A. The total suspended solids information that was used for the L/S ratio calculations can be found in Appendix B. The L/S ratio for each section was found by comparing the total solids of a local wastewater treatment plant and plastic concentrations found in Petroody et al. (2021). Locating the actual L/S ratio for each area was out of the scope for this project, so these numbers were estimated. Once these values were calculated the adsorption surface could be programmed into Visual Minteq and added into the corresponding runs.

3.4. Visual Minteq Tutorial

To use Visual Minteq one first needs to decide the constituents available in the solution and what form they are present in. Then Visual Minteq can do a variety of things. On the home screen of Visual Minteq as shown in Figure 9 the available constituents can be entered along with the ionic strength and pH of the solution. At this point if no other parameters are set Visual Minteq will run with the available constituents and show the speciation of the constituents and their amounts in mol/L. An example of a Visual Minteq output can be seen in Appendix C.

However, in order to see the adsorption to a plastic surface an adsorption surface must be created. This can be accomplished by going to the Adsorption tab in Visual Minteq. Here the k value and L/S ratio can be inputted into a Freundlich Isotherm model along with the stoichiometry of how the studied molecule interacts with the adsorption surface. For this study lead attaching to PVC was used due to being able to obtain a k value for lead to PVC from the existing literature as shown in table 4. The adsorption surface will then be added to the Visual Minteq run to see how the adsorption affects the constituents in solution.

Additionally, Visual Minteq can complete multi-problem sweeps of a solution. A multi-problem sweep can be completed by accessing the Multi-problem/Sweep tab in Visual Minteq. Visual Minteq can complete sweeps on a variety of conditions including pH, Eh, pe, fixed log activity/pressure, other species, and total concentration, any component. For this study a pH sweep was completed in order to see what effect pH had on adsorption.

Visual Minteq can do a variety of other tasks on an inputted solution. To better understand how to use Visual Minteq and its full spectrum of abilities please see the "MinteqA2/ProdefA2, A Geochemical Assessment Model For Environmental Systems: Version 3.0 User's Manual (Allison et al., 1991)." This manual gives an excellent tutorial and a scope of what Visual Minteq can accomplish.

4. RESULTS

The following are the results from the lab tests completed and the various Visual Minteq runs that were completed. These results were used to create the analysis and final conclusions on adsorption that will be explained in the next sections.

4.1. WWTP Sample Results

Tables 8-13 show the results that were acquired in lab through completing a multitude of laboratory experiments. Ammonia, electroconductivity, BOD, IC, pH, and alkalinity tests were completed in lab on the samples taken from a local wastewater treatment plant. The places where samples were collected from the influent, primary clarifiers 1 and 2, digesters 1 and 2, and the effluent. The obtained values provide an idea of what constituents are available for adsorption in wastewater treatment plants but are not representative of all wastewater treatment plants.

4.1.1. Ammonia

The results received from the ammonia test are present in Table 8. It is important to note that the blank samples showed little to no influence from outside ambient pollution. This test showed quality control checks within the necessary values to trust the results from this ammonia probe. The influent had an ammonia concentration of 32.2 mg/L, which was later used for calculations. Clarifiers 1 and 2 had ammonia concentrations of 36.5 and 39.2 mg/L respectively. The average of these values, 37.65 mg/L, was used for calculations. Digesters 1 and 2 had ammonia concentrations of 298 and 362 mg/L respectively. The average of 330 mg/L was used for calculations. The effluent had an ammonia concentration of 0.06 mg/L which was used for calculations.

Table 8.

Ammonia Test Results

Location/ Standard:	Ammonia (mg/L as NH_3):
7.5	3.7
40	43.3
QC	0.14
Influent	32.2
Influent Blank	0.16
Clarifier 1	36.5
Clarifier 2	39.2
Clarifier Blank	0.16
Digester 1	298
Digester 2	362
Digester Blank	0.11
Effluent	0.06
Effluent Blank	0.06

Note: Results from the ammonia test completed in the lab on wastewater samples.

4.1.2. Electroconductivity

The results for the electroconductivity test are present in Table 9. It is important to note that the blank samples showed little to no influence from outside ambient pollution. This test showed quality control checks within the necessary values to trust the results from this electroconductivity probe. The influent was found to have an electroconductivity of 1927 µS/cm. Clarifiers 1 and 2 had results of 2160 and 2240 µS/cm respectively. The average of these values, 2200 µS/cm, was used for calculations. Digesters 1 and 2 had electroconductivity results of 7160 and 7430 µS/cm respectively. The average of these values, 7295 µS/cm, was used for calculations. The effluent was found to have an electroconductivity of 1763 µS/cm.

Table 9.

Electroconductivity Test Results

Sample:	Electroconductivity (µS/cm):	Temperature (℃):
Nanopure Water	1	21.3
Check (792)	798	21.4
Influent	1927	19.3
Influent Field Blank	4	18.4
Clarifier 1	2160	18.8
Clarifier 2	2240	19.3
Clarifier Field Blank	3	18.8
Digester 1	7160	18.6
Digester 2	7430	18.7
Digester Field Blank	3	19.3
Effluent	1763	19.3
Effluent Field Blank	3	19.8

Note: Results from the electroconductivity test completed in the lab on wastewater samples.

4.1.3. Biological Oxygen Demand (BOD)

The results for the BOD test are present in Table 10. It is important to note that the blank samples showed little to no influence from outside ambient pollution since the results were less than 1 mg BOD/L. This test showed quality control checks within the necessary values to trust the results from this BOD test. For BOD the influent and effluent amounts were found to be 783 and 2.04 mg BOD/L respectively. For the clarifiers and digesters, the amount of sample had to be estimated due to not having an idea of what the BOD would be like in these less commonly tested areas. This resulted in only receiving a conclusive result for one of the clarifiers and one of the digesters. These results were used for the Visual Minteq inputs instead of averages. The BOD for the clarifiers and digesters was 403 and 672 mg BOD/L respectively.

Table 10.

BOD Test Results

Location:	BOD (mg BOD/L):
Blank	0
Seed	425
Influent	783
Influent Field Blank	<1
Clarifier 1	n.a.
Clarifier 2	403
Clarifier Field Blank	<1
Digester 1	672
Digester 2	n.a.
Digester Field Blank	<1
Effluent	2.04
Effluent Field Blank	<1

Note: Results from the BOD test completed in the lab on wastewater samples.

4.1.4. IC Test

The results for the Ion Chromatography (IC) test are present in Table 11. The field blanks during this test did have higher values of constituents present than other tests. However, the blank values are still small enough to be negligible. The IC test was able to test for: Fluoride, Chloride, Bromide, Nitrate, Nitrite, Sulfate, and Phosphate. Fluoride was found in the influent, clarifiers, digesters, and effluent samples. Chloride and Sulfate were found to be present in all four locations as well. Bromide was only found in the influent, clarifiers, and digesters. Nitrate was only found to be present in the digesters and effluent. Nitrite was found in the effluent. Finally, Phosphate was found in the influent, clarifiers, and effluent. Fluoride, Bromide, Nitrate, and Nitrite were found in very trace amounts, that were almost negligible. However, the values were still included to see

speciation. The clarifier and digester values were averaged for Visual Minteq input. Please see Table 11 for exact values.

Table 11.

IC Test Results

Location:	Fluoride (mg F/L):	Chloride (mg Cl/L):	Bromide (mg Br/L):	Nitrate (mg NO_3/L):	Nitrite (mg NO_2/L):	Sulfate (mg SO_4/L):	Phosphate (mg PO_4/L):
Influent	1.93	363.53	1.46	n.a.	n.a.	173.59	52.71
Influent Field Blank	0.85	3.60	n.a.	0.39	0.86	1.84	n.a.
Clarifier 1	2.12	422.74	1.44	n.a.	n.a.	160.38	58.24
Clarifier 2	2.18	436.00	1.45	n.a.	n.a.	145.83	52.50
Clarifier Field Blank	n.a.	2.91	n.a.	0.36	0.86	1.49	n.a.
Digester 1	0.96	203.25	1.60	0.36	n.a.	n.a.	n.a.
Digester 2	0.99	195.88	1.56	0.43	n.a.	12.25	n.a.
Digester Field Blank	1.28	3.77	n.a.	0.41	n.a.	1.99	n.a.
Effluent	1.85	384.06	n.a.	35.07	16.20	168.89	28.37
Effluent Field Blank	1.16	2.72	n.a.	0.38	n.a.	1.68	n.a.

Note: Results from the IC test completed in the lab on wastewater samples.

4.1.5. pH Test

The results for the pH test are shown in Table 12. The blank samples for this tests had pHs ranging from 4- 5.8 meaning they were consistent. The pH for the blank sample is lower due to them being created using nanopure water. The various locations all had neutral pH values. The influent, clarifier 1, clarifier 2, digester 1, and effluent had pH values of 7.1, 7.1, 7.1, 7.2, and 7.3 respectively. The clarifiers used 7.1 for the pH for Visual Minteq input due to it being the same for both clarifiers. The pH was only found for digester 1 due to lack of sample for digester 2 and this value of 7.2 was persumed to be the same for both since there was little variation and used for the digester inputs for Visual Minteq.

Table 12.

pH Test Results

Location:	pH:
Influent	7.1
Influent Field Blank	5.7
Clarifier 1	7.1
Clarifier 2	7.1
Clarifier Field Blank	5.7
Digester 1	7.2
Digester Field Blank	5.8
Effluent	7.3
Effluent Field Blank	4.0

Note: Results from the pH test completed in the lab on wastewater samples.

4.1.6. Alkalinity Test

The results for the alkalinity test are present in Table 13. It is important to note that the blank samples showed little to no influence from outside ambient pollution since the results were 0 mg/L as $CaCO_3$ for all the blanks. There were two alkalinity tests completed on each sample in order to obtain an average. The averages for the influent, clarifier 1, clarifier 2, digester 1, digester 2, and effluent were 6.65, 7.55, 7.6, >25, >25, and 2.05 mg/L as $CaCO_3$ respectively.

Table 13.

Alkalinity Test Results

Location:	Volume (ml):	Alkalinity 1 (mg/L as $CaCO_3$):	Alkalinity 2 (mg/L as $CaCO_3$):
Influent	20	6.6	6.7
Influent Field Blank	20	0	0
Clarifier 1	20	7.5	7.6
Clarifier 2	20	7.6	7.6
Clarifier Field Blank	20	0	0
Digester 1	20	>25	>25
Digester 2	20	>25	>25
Digester Field Blank	20	0	0
Effluent	20	2	2.1
Effluent Field Blank	20	0	0

Note: Results from the alkalinity test completed in the lab on wastewater samples.

4.2. Visual Minteq Input Values

Tables 14-17 show what information was inputted into Visual Minteq at each location of the wastewater treatment plant. These values were inputted into the geochemical equilibrium model: Visual Minteq. The values are given in mg/L and mol/L due to the fact that the lab results were given in mg/L and the Visual Minteq results are given in mol/L. H^{+1} and CO_3^{-2} both appear as 0 mg/L due to the fact that they are automatically added to Visual Minteq in order to represent atmospheric conditions. DOM1 is also 0 mg/L because that is how it is added into Visual Minteq when DOC is added in. For these input values several values had to be converted from the lab tests. The ionic strength needed to be converted to ionic strength. The calculations for this conversion can be found in Appendix A. Ammonia needed to be converted to ammonium and these conversions can also be seen in Appendix A. Additionally, in Appendix A are the L/S ratio calculations. The L/S ratios were calculated using the total suspended solids

and knowledge acquired from Petroody et al. (2021). These calculations can also be seen in Appendix A. DOC was used to represent BOD. BOD was not an available constituent in Visual Minteq. BOD was presumed to be the same at Total Organic Carbon (TOC) from Metcalf et al. (1991). DOC was assumed to be 50% of TOC due to TOC= DOC+ NDOC (Rakocz & Rosińska, 2017). This explains why the DOC values are 50% of the BOD values found in the lab.

Table 14.

Influent Visual Minteq Input

Constituent:	mg/L:	mol/L:
H +1	0	0
NH4 +1	34.1	1.89E-03
CO3 -2	0	0
F -1	1.9	1.02E-04
Cl -1	363.5	1.03E-02
Br -1	1.5	1.83E-05
SO4 -2	173.6	1.81E-03
PO4 -3	52.7	5.55E-04
Ca +2	20.0	4.99E-04
Fe +2	0.1	1.79E-06
K +1	2.0	5.11E-05
Na +1	20.0	8.70E-04
Mg +2	3.0	1.23E-04
DOC	391.5	3.26E-02
DOM1	0	0
Pb +2	10.0	4.83E-05
L/S Ratio:	30.06	
Ionic Strength:	0.031	
pH:	7.1	

Note: The Visual Mintequ input values for the influent for the various runs.

Table 15.

Clarifier Visual Mintequ Input

Constituent:	mg/L:	mol/L:
H +1	0	0
NH4 +1	39.88	2.21E-03
CO3 -2	0	0
F -1	2.15	1.13E-04
Cl -1	429.37	1.21E-02
Br -1	1.45	1.81E-05
SO4 -2	153.10	1.59E-03
PO4 -3	55.37	5.83E-04
Ca +2	17.24	4.30E-04
Fe +2	0.07	1.20E-06
K +1	1.98	5.06E-05
Na +1	19.79	8.61E-04
Mg +2	2.59	1.06E-04
DOC	201.5	1.68E-02
DOM1	0	0
Pb +2	10.00	4.83E-05
L/S Ratio:	100.87	
Ionic Strength:	0.035	
pH:	7.1	

Note: The Visual Mintequ input values for the clarifiers for the various runs.

Table 16.

Digester Visual Mintequ Input

Constituent:	mg/L:	mol/L:
H +1	0	0
NH4 +1	349.50	1.94E-02
CO3 -2	0	0
F -1	1.96	1.03E-04
Cl -1	399.12	1.13E-02
Br -1	3.16	4.58E-05
SO4 -2	24.50	2.55E-04
NO3 -	0.78	5.57E-05
Ca +2	15.06	3.76E-04
Fe +2	0.05	8.08E-07
K +1	1.96	5.00E-05
Na +1	19.57	8.51E-04
Mg +2	2.25	9.27E-05
DOC	336.5	2.80E-02
DOM1	0	0
Pb +2	10.00	4.83E-05
L/S Ratio:	77.23	
Ionic Strength:	0.118	
pH:	7.2	

Note: The Visual Mintequ input values for the digesters for the various runs.

Table 17.

Effluent Visual Mintequ Input

Constituent:	mg/L:	mol/L:
H +1	0	0
NH4 +1	0.06	3.49E-06
CO3 -2	0	0
F -1	1.85	9.74E-05
Cl -1	384.06	1.08E-02
NO3 -	35.07	2.50E-03
SO4 -2	168.89	1.76E-03
PO4 -3	28.37	2.99E-04
NO2 -	16.2	1.16E-03
Ca +2	15.06	3.76E-04
Fe +2	0.05	8.08E-07
K +1	1.96	5.00E-05
Na +1	19.57	8.51E-04
Mg +2	2.25	9.27E-05
DOC	1.02	8.50E-05
DOM1	0	0
Pb +2	10.00	4.83E-05
L/S Ratio:	2516.28	
Ionic Strength:	0.028	
pH:	7.3	

Note: The Visual Mintequ input values for the effluent for the various runs.

4.3. Percent of Change- Visual Minteq Runs

Tables 18 through 21 show the results for the main input constituents from the various Visual Minteq runs. These tables additionally show the percent of change between each run and the original. The percent change after the no additions run shows the percent difference from the input values to the output from a Visual Minteq run. The additional percent changed columns compare the different Visual Minteq Runs to the run without additions, to see if there is a change when DOC, lead, or the plastic adsorption surface are added. As stated earlier the Visual Minteq runs that were completed are: with

no additions; with DOC added; with DOC and lead added; with DOC, lead, and the plastic adsorption surface added; with lead and the plastic adsorption surface added; and with just lead added. Please see the following tables for the results from these runs and the following discussion to explain the precents of change.

Table 18.

Influent Percent Change Visual Mintequ Runs

Constituent:	mol/L:	No Additions:	% Changed:	DOC Added:	% Changed:	DOC+ 10mg Pb Added:	% Changed:	DOC+10mgPb + Adsorption Added:	% Changed:	10mg Pb+ Adsorption Added:	% Changed:	10mg Pb Added:	% Changed:
H +1	0	9.37E-08		9.37E-08	0	9.37E-08	0	9.37E-08	0	9.37E-08	0	9.37E-08	0
NH4 +1	1.89E-03	1.86E-03	-1.54	1.86E-03	-0.02	1.86E-03	-0.02	1.86E-03	-0.02	1.86E-03	0	1.86E-03	0.01
CO3 -2	0	8.26E-08		8.26E-08	0	8.26E-08	0	8.26E-08	0	8.26E-08	0	8.26E-08	0
F -1	1.02E-04	1.01E-04	-0.81	1.01E-04	0.36	1.01E-04	0.34	1.01E-04	0.36	1.01E-04	0	1.01E-04	-0.19
Cl -1	1.03E-02	1.02E-02	-0.11	1.02E-02	0.05	1.02E-02	0.05	1.02E-02	0.05	1.02E-02	0	1.02E-02	-0.05
Br -1	1.83E-05	1.83E-05	0.001	1.83E-05	0	1.83E-05	0	1.83E-05	0	1.83E-05	0	1.83E-05	-0.07
SO4 -2	1.81E-03	1.73E-03	-4.23	1.77E-03	2.14	1.77E-03	2.07	1.77E-03	2.14	1.73E-03	-0.01	1.72E-03	-0.34
PO4 -3	5.55E-04	3.64E-09	-100.00	3.75E-09	2.81	3.74E-09	2.70	3.75E-09	2.81	3.64E-09	0	3.62E-09	-0.49
Ca +2	4.99E-04	4.30E-04	-13.80	9.15E-05	-78.74	1.01E-04	-76.44	9.15E-05	-78.74	4.30E-04	0	4.30E-04	0.05
Fe +2	1.79E-06	1.20E-06	-33.19	1.19E-06	-0.87	1.19E-06	-0.84	1.19E-06	-0.87	1.20E-06	-0.01	1.20E-06	0.15
K +1	5.11E-05	5.06E-05	-1.14	5.06E-05	-0.02	5.06E-05	-0.02	5.06E-05	-0.02	5.06E-05	0	5.06E-05	0
Na +1	8.70E-04	8.61E-04	-1.07	8.60E-04	-0.02	8.60E-04	-0.02	8.60E-04	-0.02	8.61E-04	0	8.61E-04	0
Mg +2	1.23E-04	1.06E-04	-13.74	7.75E-05	-27.17	8.02E-05	-24.64	7.75E-05	-27.17	1.06E-04	-0.01	1.06E-04	0.05
DOC	3.26E-02			3.26E-02		3.26E-02		3.26E-02					
DOM1	0			2.38E-03		2.34E-03		2.38E-03					
Pb +2	4.83E-05					6.42E-08		2.68E-21		1.25E-18		2.63E-05	
ads-Pb-PVC								4.83E-05		4.83E-05			

Note: Information from Visual Minteq runs showing changes in constituents for influent. Results in mol/L.

Table 19.

Clarifier Percent Change Visual Minteq Runs

Clarifiers													
Input:		Results From Respective Runs (mol/L):											
Constituent:	mol/L:	No Additions:	% Changed:	DOC Added:	% Changed:	DOC+ 10mg Pb Added:	% Changed:	DOC+10mgPb + Adsorption Added:	% Changed:	10mg Pb+ Adsorption Added:	% Changed:	10mg Pb Added:	% Changed:
H +1	0	9.44E-08		9.44E-08	0	9.44E-08	0	9.44E-08	0	9.44E-08	0	9.44E-08	0
NH4 +1	2.21E-03	2.18E-03	-1.40	2.18E-03	-0.01	2.18E-03	-0.01	2.18E-03	-0.01	2.18E-03	-0.005	2.18E-03	-0.005
CO3 -2	0	8.53E-08		8.53E-08	0	8.53E-08	0	8.53E-08	0	8.53E-08	0	8.53E-08	0
F -1	1.13E-04	1.12E-04	-0.70	1.13E-04	0.19	1.13E-04	0.17	1.13E-04	0.19	1.12E-04	0	1.12E-04	0
Cl -1	1.21E-02	1.21E-02	-0.10	1.21E-02	0.03	1.21E-02	0.02	1.21E-02	0.03	1.21E-02	0	1.21E-02	0
Br -1	1.81E-05	1.81E-05	0.001	1.81E-05	0	1.81E-05	0	1.81E-05	0	1.81E-05	0	1.81E-05	0
SO4 -2	1.59E-03	1.53E-03	-3.83	1.55E-03	1.23	1.55E-03	1.12	1.55E-03	1.23	1.53E-03	-0.01	1.53E-03	-0.01
PO4 -3	5.83E-04	4.05E-09	-100.00	4.12E-09	1.61	4.11E-09	1.47	4.12E-09	1.61	4.05E-09	-0.002	4.05E-09	0
Ca +2	4.30E-04	3.76E-04	-12.62	1.62E-04	-57.03	1.79E-04	-52.41	1.61E-04	-57.04	3.76E-04	-0.01	3.76E-04	-0.003
Fe +2	1.20E-06	8.08E-07	-32.43	8.04E-07	-0.50	8.05E-07	-0.45	8.04E-07	-0.50	8.08E-07	-0.01	8.08E-07	-0.001
K +1	5.06E-05	5.00E-05	-1.11	5.00E-05	-0.01	5.00E-05	-0.01	5.00E-05	-0.01	5.00E-05	-0.002	5.00E-05	-0.002
Na +1	8.61E-04	8.51E-04	-1.07	8.51E-04	-0.01	8.51E-04	-0.01	8.51E-04	-0.01	8.51E-04	-0.001	8.51E-04	0
Mg +2	1.06E-04	9.27E-05	-12.95	8.17E-05	-11.79	8.34E-05	-9.99	8.17E-05	-11.79	9.27E-05	-0.005	9.27E-05	-0.001
DOC	1.68E-02			1.68E-02		1.68E-02		1.68E-02					
DOM1	0			1.19E-03		1.16E-03		1.19E-03					
Pb +2	4.83E-05					1.91E-07		2.53E-20		4.24E-18		5.49E-17	
ads-Pb-PVC								4.83E-05		4.83E-05			

Note: Information from Visual Minteq runs showing changes in constituents for the clarifiers. Results in mol/L.

Table 20.

Digester Percent Change Visual Minteq Runs

Digesters													
Input:		Results From Respective Runs (mol/L):											
Constituent:	mol/L:	No Additions:	% Changed:	DOC Added:	% Changed:	DOC+ 10mg Pb Added:	% Changed:	DOC+10mgPb + Adsorption Added:	% Changed:	10mg Pb+ Adsorption Added:	% Changed:	10mg Pb Added:	% Changed:
H +1	0	8.18E-08		8.18E-08	0	8.18E-08	0	8.18E-08	0	8.18E-08	0	8.18E-08	0
NH4 +1	1.94E-02	1.92E-02	-0.76	1.92E-02	-0.01	1.92E-02	-0.01	1.92E-02	-0.01	1.92E-02	-0.01	1.92E-02	0
CO3 -2	0	1.90E-07		1.90E-07	0	1.90E-07	0	1.90E-07	0	1.90E-07	0	1.90E-07	0
F -1	1.03E-04	1.03E-04	-0.49	1.03E-04	0.17	1.03E-04	0.15	1.03E-04	0.17	1.03E-04	0	1.02E-04	-0.17
Cl -1	1.13E-02	1.13E-02	-0.07	1.13E-02	0.02	1.13E-02	0.02	1.13E-02	0.02	1.13E-02	0	1.12E-02	-0.04
Br -1	4.58E-05	1.98E-05	-56.83	1.98E-05	0	1.98E-05	0	1.98E-05	0	1.98E-05	0	1.98E-05	-0.06
SO4 -2	2.55E-04	2.35E-04	-8.02	2.36E-04	0.67	2.36E-04	0.63	2.36E-04	0.67	2.35E-04	-0.01	2.34E-04	-0.19
NO3 -	5.57E-05	5.57E-05	-0.06	5.57E-05	0.03	5.57E-05	0.03	5.57E-05	0.03	5.57E-05	0	5.56E-05	-0.02
Ca +2	3.76E-04	3.69E-04	-1.76	1.19E-04	-67.70	1.33E-04	-63.92	1.19E-04	-67.71	3.69E-04	-0.01	3.69E-04	0
Fe +2	8.08E-07	7.95E-07	-1.66	7.95E-07	-0.01	7.95E-07	-0.01	7.95E-07	-0.01	7.95E-07	-0.01	7.95E-07	-0.001
K +1	5.00E-05	4.98E-05	-0.39	4.98E-05	-0.002	4.98E-05	-0.002	4.98E-05	-0.002	4.98E-05	-0.002	4.98E-05	0
Na +1	8.51E-04	8.48E-04	-0.38	8.48E-04	-0.001	8.48E-04	-0.001	8.48E-04	-0.001	8.48E-04	-0.001	8.48E-04	0
Mg +2	9.27E-05	9.05E-05	-2.38	7.49E-05	-17.25	7.69E-05	-14.98	7.49E-05	-17.25	9.04E-05	-0.01	9.05E-05	-0.001
DOC	2.80E-02			2.80E-02		2.80E-02		2.80E-02					
DOM1	0			2.14E-03		2.11E-03		2.14E-03					
Pb +2	4.83E-05					1.34E-07		1.38E-20		4.04E-18		3.30E-05	
ads-Pb-PVC								4.83E-05		4.83E-05			

Note: Information from Visual Minteq runs showing changes in constituents for the digesters. Results in mol/L.

Table 21.

Effluent Percent Change Visual Minteq Runs

Effluent													
Input:		Results From Respective Runs (mol/L):											
Constituent:	mol/L:	No Additions:	% Changed:	DOC Added:	% Changed:	DOC+ 10mg Pb Added:	% Changed:	DOC+10mgPb + Adsorption Added:	% Changed:	10mg Pb+ Adsorption Added:	% Changed:	10mg Pb Added:	% Changed:
H +1	0	5.87E-08		5.87E-08	0	5.87E-08	0	5.87E-08	0	5.87E-08	0	5.87E-08	0
NH4 +1	3.49E-06	3.43E-06	-1.90	3.43E-06	0	3.43E-06	0.003	3.43E-06	0	3.43E-06	0	3.43E-06	0.003
CO3 -2	0	2.02E-07		2.02E-07	0	2.02E-07	0	2.02E-07	0	2.02E-07	0	2.02E-07	0
F -1	9.74E-05	9.67E-05	-0.64	9.68E-05	0.001	9.66E-05	-0.15	9.67E-05	0	9.67E-05	-0.001	9.66E-05	-0.16
Cl -1	1.08E-02	1.08E-02	-0.09	1.08E-02	0	1.08E-02	-0.04	1.08E-02	0	1.08E-02	0	1.08E-02	-0.05
NO3 -	2.50E-03	2.50E-03	-0.07	2.50E-03	0	2.50E-03	-0.02	2.50E-03	0	2.50E-03	0	2.50E-03	-0.02
SO4 -2	1.76E-03	1.71E-03	-2.68	1.71E-03	0.01	1.71E-03	-0.27	1.71E-03	0	1.71E-03	-0.01	1.71E-03	-0.29
PO4 -3	2.99E-04	3.57E-09	-100.00	3.57E-09	0.01	3.55E-09	-0.45	3.57E-09	0.01	3.57E-09	-0.003	3.55E-09	-0.48
NO2 -	1.16E-03	1.16E-03	-0.01	1.16E-03	0	1.15E-03	-0.34	1.16E-03	0	1.16E-03	0	1.15E-03	-0.36
Ca +2	3.76E-04	3.25E-04	-13.55	3.23E-04	-0.45	3.25E-04	-0.03	3.23E-04	-0.45	3.25E-04	-0.01	3.25E-04	0.04
Fe +2	8.08E-07	5.92E-07	-26.76	5.92E-07	-0.002	5.93E-07	0.10	5.92E-07	-0.01	5.92E-07	-0.01	5.93E-07	0.10
K +1	5.00E-05	4.94E-05	-1.23	4.94E-05	0	4.94E-05	0	4.94E-05	-0.002	4.94E-05	-0.002	4.94E-05	0.002
Na +1	8.51E-04	8.42E-04	-1.07	8.42E-04	0	8.42E-04	0.001	8.42E-04	-0.001	8.42E-04	-0.001	8.42E-04	0.002
Mg +2	9.27E-05	8.07E-05	-12.92	8.07E-05	-0.05	8.07E-05	0.02	8.07E-05	-0.05	8.07E-05	-0.01	8.07E-05	0.03
DOC	8.50E-05			8.50E-05		8.50E-05		8.50E-05					
DOM1	0			5.60E-06		4.04E-06		5.60E-06					
Pb +2	4.83E-05					1.96E-05		5.77E-17		8.35E-17		2.09E-05	
ads-Pb-PVC								4.83E-05		4.83E-05			

Note: Information from Visual Minteq runs showing changes in constituents for effluent. Results in mol/L.

4.4. Speciation of Constituents

Table 22 shows the species that were created throughout the different Visual Minteq runs. These results are from the run for each location that included DOC, 10mg of lead, and the plastic adsorption surface. There were 108 species found in the influent and clarifiers, 92 species found in the digesters, and 115 species were found in the effluent. The grey boxes in Table 22 show the missing species for each location.

Table 22.

Visual Minteq Speciation

Species Created in Each Area			
Influent (108 Species):	Clarifiers (108 Species):	Digesters (92 Species):	Effluent (115 Species):
ads-Pb-PVC	ads-Pb-PVC	ads-Pb-PVC	ads-Pb-PVC
Br-1	Br-1	Br-1	
Ca DOM1	Ca DOM1	Ca DOM1	Ca DOM1
Ca(NH3)2+2	Ca(NH3)2+2	Ca(NH3)2+2	Ca(NH3)2+2
		Ca(NO3)2	Ca(NO3)2
Ca+2	Ca+2	Ca+2	Ca+2
CaCl+	CaCl+	CaCl+	CaCl+
CaCO3 (aq)	CaCO3 (aq)	CaCO3 (aq)	CaCO3 (aq)
CaF+	CaF+	CaF+	CaF+
CaH2PO4+	CaH2PO4+		CaH2PO4+
CaHCO3+	CaHCO3+	CaHCO3+	CaHCO3+
CaHPO4 (aq)	CaHPO4 (aq)		CaHPO4 (aq)
CaNH3+2	CaNH3+2	CaNH3+2	CaNH3+2
		CaNO3+	CaNO3+
CaOH+	CaOH+	CaOH+	CaOH+
CaPO4-	CaPO4-		CaPO4-
CaSO4 (aq)	CaSO4 (aq)	CaSO4 (aq)	CaSO4 (aq)
Cl-1	Cl-1	Cl-1	Cl-1
CO3-2	CO3-2	CO3-2	CO3-2
DOC (Gaussian DOM)	DOC (Gaussian DOM)	DOC (Gaussian DOM)	DOC (Gaussian DOM)
DOM1	DOM1	DOM1	DOM1
F-1	F-1	F-1	F-1
Fe(NH3)2+2	Fe(NH3)2+2	Fe(NH3)2+2	Fe(NH3)2+2
Fe(NH3)3+2	Fe(NH3)3+2	Fe(NH3)3+2	Fe(NH3)3+2
Fe(NH3)4+2	Fe(NH3)4+2	Fe(NH3)4+2	Fe(NH3)4+2
Fe(OH)2 (aq)	Fe(OH)2 (aq)	Fe(OH)2 (aq)	Fe(OH)2 (aq)
Fe(OH)3-	Fe(OH)3-	Fe(OH)3-	Fe(OH)3-
Fe+2	Fe+2	Fe+2	Fe+2
FeCl+	FeCl+	FeCl+	FeCl+
FeF+	FeF+	FeF+	FeF+
FeH2PO4+	FeH2PO4+		FeH2PO4+
FeHCO3+	FeHCO3+	FeHCO3+	FeHCO3+
FeHPO4 (aq)	FeHPO4 (aq)		FeHPO4 (aq)
FeNH3+2	FeNH3+2	FeNH3+2	FeNH3+2
FeOH+	FeOH+	FeOH+	FeOH+
FeSO4 (aq)	FeSO4 (aq)	FeSO4 (aq)	FeSO4 (aq)

Influent:	Clarifiers:	Digesters:	Effluent:
H DOM1	H DOM1	H DOM1	H DOM1
H+1	H+1	H+1	H+1
H2CO3* (aq)	H2CO3* (aq)	H2CO3* (aq)	H2CO3* (aq)
H2PO4-	H2PO4-		H2PO4-
H3PO4	H3PO4		H3PO4
HCO3-	HCO3-	HCO3-	HCO3-
HF (aq)	HF (aq)	HF (aq)	HF (aq)
HF2-	HF2-	HF2-	HF2-
			HNO2 (aq)
HPO4-2	HPO4-2		HPO4-2
HSO4-	HSO4-	HSO4-	HSO4-
K+1	K+1	K+1	K+1
K2HPO4 (aq)	K2HPO4 (aq)		K2HPO4 (aq)
K2PO4-	K2PO4-		K2PO4-
KCl (aq)	KCl (aq)	KCl (aq)	KCl (aq)
KF (aq)	KF (aq)	KF (aq)	KF (aq)
KH2PO4 (aq)	KH2PO4 (aq)		KH2PO4 (aq)
KHPO4-	KHPO4-		KHPO4-
		KNO3 (aq)	KNO3 (aq)
KOH (aq)	KOH (aq)	KOH (aq)	KOH (aq)
KPO4-2	KPO4-2		KPO4-2
KSO4-	KSO4-	KSO4-	KSO4-
Mg DOM1	Mg DOM1	Mg DOM1	Mg DOM1
Mg(NH3)2+2	Mg(NH3)2+2	Mg(NH3)2+2	Mg(NH3)2+2
Mg+2	Mg+2	Mg+2	Mg+2
Mg2CO3+2	Mg2CO3+2	Mg2CO3+2	Mg2CO3+2
MgCl+	MgCl+	MgCl+	MgCl+
MgCO3 (aq)	MgCO3 (aq)	MgCO3 (aq)	MgCO3 (aq)
MgF+	MgF+	MgF+	MgF+
MgHCO3+	MgHCO3+	MgHCO3+	MgHCO3+
MgHPO4 (aq)	MgHPO4 (aq)	MgOH+	MgHPO4 (aq)
MgOH+	MgOH+		MgOH+
MgPO4-	MgPO4-		MgPO4-
MgSO4 (aq)	MgSO4 (aq)	MgSO4 (aq)	MgSO4 (aq)
Na+1	Na+1	Na+1	Na+1
Na2HPO4 (aq)	Na2HPO4 (aq)		Na2HPO4 (aq)
Na2PO4-	Na2PO4-		Na2PO4-
NaCl (aq)	NaCl (aq)	NaCl (aq)	NaCl (aq)
NaCO3-	NaCO3-	NaCO3-	NaCO3-
NaF (aq)	NaF (aq)	NaF (aq)	NaF (aq)
NaH2PO4 (aq)	NaH2PO4 (aq)		NaH2PO4 (aq)
NaHCO3 (aq)	NaHCO3 (aq)	NaHCO3 (aq)	NaHCO3 (aq)

Influent:	Clarifiers:	Digesters:	Effluent:
NaHPO4-	NaHPO4-		NaHPO4-
		NaNO3 (aq)	NaNO3 (aq)
NaOH (aq)	NaOH (aq)	NaOH (aq)	NaOH (aq)
NaPO4-2	NaPO4-2		NaPO4-2
NaSO4-	NaSO4-	NaSO4-	NaSO4-
NH3 (aq)	NH3 (aq)	NH3 (aq)	NH3 (aq)
NH4+1	NH4+1	NH4+1	NH4+1
NH4SO4-	NH4SO4-	NH4SO4-	NH4SO4-
			NO2-1
		NO3-1	NO3-1
OH-	OH-	OH-	OH-
Pb DOM1	Pb DOM1	Pb DOM1	Pb DOM1
Pb(CO3)2-2	Pb(CO3)2-2	Pb(CO3)2-2	Pb(CO3)2-2
			Pb(NO2)2 (aq)
		Pb(NO3)2 (aq)	Pb(NO3)2 (aq)
Pb(OH)2 (aq)	Pb(OH)2 (aq)	Pb(OH)2 (aq)	Pb(OH)2 (aq)
Pb(OH)3-	Pb(OH)3-	Pb(OH)3-	Pb(OH)3-
Pb(SO4)2-2	Pb(SO4)2-2	Pb(SO4)2-2	Pb(SO4)2-2
Pb+2	Pb+2	Pb+2	Pb+2
Pb2OH+3	Pb2OH+3	Pb2OH+3	Pb2OH+3
Pb3(OH)4+2	Pb3(OH)4+2	Pb3(OH)4+2	Pb3(OH)4+2
Pb4(OH)4+4	Pb4(OH)4+4	Pb4(OH)4+4	Pb4(OH)4+4
PbBr+	PbBr+	PbBr+	
PbBr2 (aq)	PbBr2 (aq)	PbBr2 (aq)	
PbBr3-	PbBr3-	PbBr3-	
PbCl+	PbCl+	PbCl+	PbCl+
PbCl2 (aq)	PbCl2 (aq)	PbCl2 (aq)	PbCl2 (aq)
PbCl3-	PbCl3-	PbCl3-	PbCl3-
PbCl4-2	PbCl4-2	PbCl4-2	PbCl4-2
PbCO3 (aq)	PbCO3 (aq)	PbCO3 (aq)	PbCO3 (aq)
PbF+	PbF+	PbF+	PbF+
PbF2 (aq)	PbF2 (aq)	PbF2 (aq)	PbF2 (aq)
PbH2PO4+	PbH2PO4+		PbH2PO4+
PbHCO3+	PbHCO3+	PbHCO3+	PbHCO3+
PbHPO4 (aq)	PbHPO4 (aq)		PbHPO4 (aq)
			PbNO2+
		PbNO3+	PbNO3+
PbOH+	PbOH+	PbOH+	PbOH+
PbSO4 (aq)	PbSO4 (aq)	PbSO4 (aq)	PbSO4 (aq)
PO4-3	PO4-3		PO4-3
SO4-2	SO4-2	SO4-2	SO4-2

4.5. pH Sweep

Tables 23-26 show the results for pH sweeps that were completed on the influent, clarifier, digester, and effluent data. These sweeps were completed in order to understand how pH affects adsorption to the plastic surface. Figures 10-13 show a graphical representation of the data from Tables 23-26.

Table 23.

Influent pH Sweep Results

Influent pH Sweep (mol/L)						
Problem no.	pH	Pb+2	Pb+2	Pb+2	Pb+2	Pb+2
		Concentration	Log Concentration	Total dissolved	Total sorbed	Bound to DOM
1	3	1.68E-19	-18.77	2.30E-18	4.83E-05	2.06E-18
2	3.5	7.02E-20	-19.15	2.30E-18	4.83E-05	2.20E-18
3	4	3.04E-20	-19.52	2.30E-18	4.83E-05	2.26E-18
4	4.5	1.43E-20	-19.84	2.30E-18	4.83E-05	2.28E-18
5	5	7.60E-21	-20.12	2.30E-18	4.83E-05	2.29E-18
6	5.5	4.68E-21	-20.33	2.30E-18	4.83E-05	2.29E-18
7	6	3.41E-21	-20.47	2.30E-18	4.83E-05	2.29E-18
8	6.5	2.90E-21	-20.54	2.30E-18	4.83E-05	2.30E-18
9	7	2.70E-21	-20.57	2.30E-18	4.83E-05	2.29E-18
10	7.5	2.62E-21	-20.58	2.30E-18	4.83E-05	2.29E-18
11	8	2.57E-21	-20.59	2.30E-18	4.83E-05	2.28E-18
12	8.5	2.38E-21	-20.62	2.30E-18	4.83E-05	2.15E-18
13	9	1.10E-21	-20.96	2.30E-18	4.83E-05	1.07E-18
14	9.5	3.32E-23	-22.48	2.30E-18	4.83E-05	4.48E-20
15	10	3.61E-25	-24.44	2.30E-18	4.83E-05	1.06E-21

Note: Results from the Visual Minteq pH sweep for the influent. Results in mol/L.

Table 24.

Clarifier pH Sweep Results

Clarifier pH Sweep (mol/L)						
Problem no.	pH	Pb+2	Pb+2	Pb+2	Pb+2	Pb+2
		Concentration	Log Concentration	Total dissolved	Total sorbed	Bound to DOM
1	3	1.05E-18	-17.98	7.72E-18	4.83E-05	6.24E-18
2	3.5	4.62E-19	-18.34	7.72E-18	4.83E-05	7.06E-18
3	4	2.05E-19	-18.69	7.72E-18	4.83E-05	7.42E-18
4	4.5	9.92E-20	-19.00	7.72E-18	4.83E-05	7.57E-18
5	5	5.52E-20	-19.26	7.72E-18	4.83E-05	7.64E-18
6	5.5	3.69E-20	-19.43	7.72E-18	4.83E-05	7.66E-18
7	6	2.94E-20	-19.53	7.72E-18	4.83E-05	7.67E-18
8	6.5	2.66E-20	-19.58	7.72E-18	4.83E-05	7.68E-18
9	7	2.55E-20	-19.59	7.72E-18	4.83E-05	7.67E-18
10	7.5	2.49E-20	-19.60	7.72E-18	4.83E-05	7.65E-18
11	8	2.41E-20	-19.62	7.72E-18	4.83E-05	7.52E-18
12	8.5	2.03E-20	-19.69	7.72E-18	4.83E-05	6.51E-18
13	9	5.26E-21	-20.28	7.72E-18	4.83E-05	1.89E-18
14	9.5	1.13E-22	-21.95	7.72E-18	4.83E-05	6.33E-20
15	10	1.21E-24	-23.92	7.72E-18	4.83E-05	1.69E-21

Note: Results from the Visual Minteq pH sweep for the clarifiers. Results in mol/L.

Table 25.

Digester pH Sweep Results

Digester pH Sweep (mol/L)						
Problem no.	pH	Pb+2	Pb+2	Pb+2	Pb+2	Pb+2
		Concentration	Log Concentration	Total dissolved	Total sorbed	Bound to DOM
1	3	9.09E-19	-18.04	5.91E-18	4.83E-05	4.85E-18
2	3.5	4.00E-19	-18.40	5.91E-18	4.83E-05	5.44E-18
3	4	1.76E-19	-18.76	5.91E-18	4.83E-05	5.70E-18
4	4.5	8.19E-20	-19.09	5.91E-18	4.83E-05	5.81E-18
5	5	4.25E-20	-19.37	5.91E-18	4.83E-05	5.86E-18
6	5.5	2.55E-20	-19.59	5.91E-18	4.83E-05	5.88E-18
7	6	1.81E-20	-19.74	5.91E-18	4.83E-05	5.89E-18
8	6.5	1.51E-20	-19.82	5.91E-18	4.83E-05	5.89E-18
9	7	1.40E-20	-19.85	5.91E-18	4.83E-05	5.89E-18
10	7.5	1.36E-20	-19.87	5.91E-18	4.83E-05	5.88E-18
11	8	1.34E-20	-19.87	5.91E-18	4.83E-05	5.83E-18
12	8.5	1.22E-20	-19.91	5.91E-18	4.83E-05	5.38E-18
13	9	4.15E-21	-20.38	5.91E-18	4.83E-05	1.92E-18
14	9.5	8.86E-23	-22.05	5.91E-18	4.83E-05	5.49E-20
15	10	9.36E-25	-24.03	5.91E-18	4.83E-05	1.26E-21

Note: Results from the Visual Minteq pH sweep for the digesters. Results in mol/L.

Table 26.

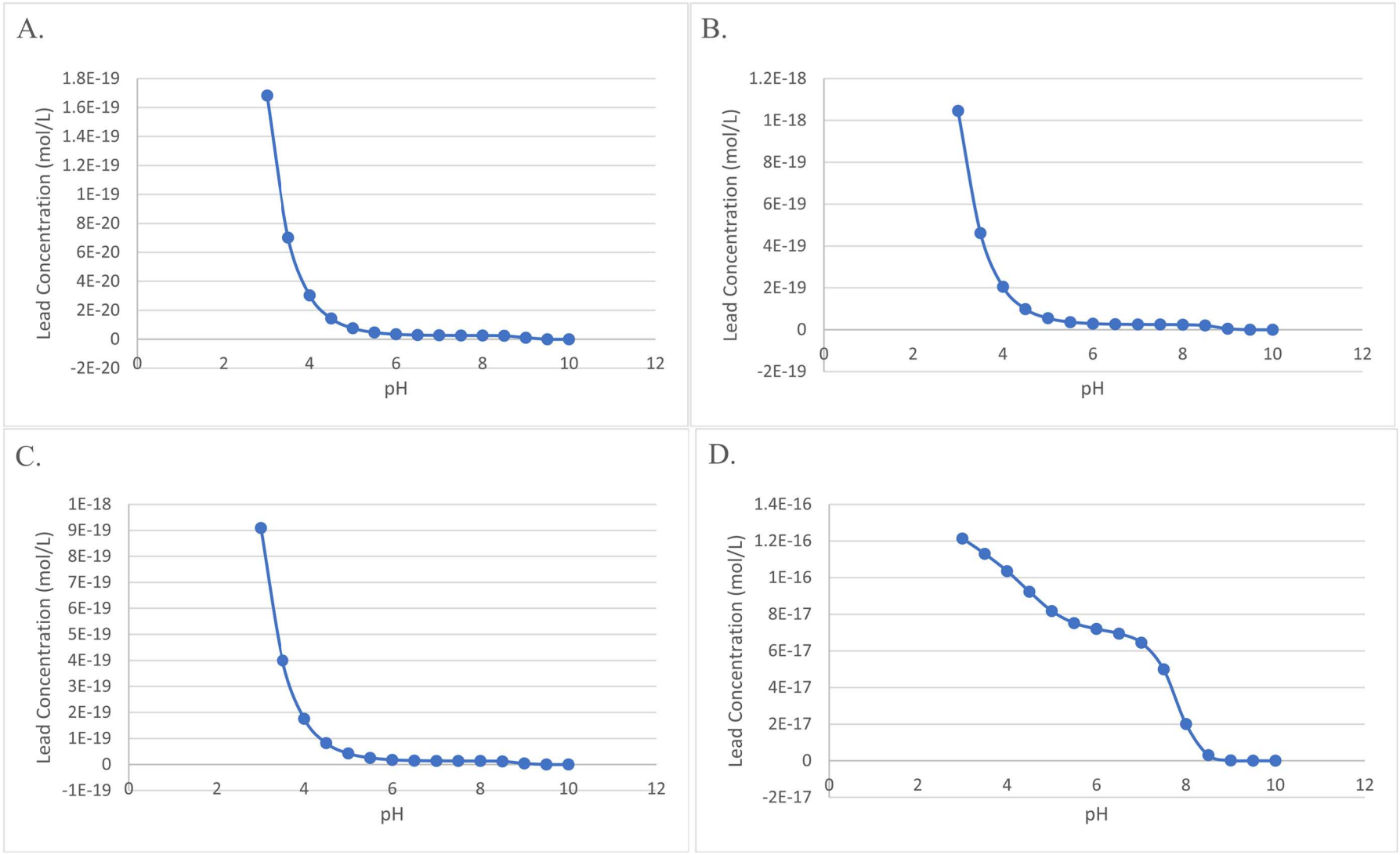
Effluent pH Sweep Results

Effluent pH Sweep (mol/L)						
Problem no.	pH	Pb+2	Pb+2	Pb+2	Pb+2	Pb+2
		Concentration	Log Concentration	Total dissolved	Total sorbed	Bound to DOM
1	3	1.21E-16	-15.92	1.93E-16	4.83E-05	4.07E-18
2	3.5	1.13E-16	-15.95	1.92E-16	4.83E-05	9.71E-18
3	4	1.04E-16	-15.99	1.92E-16	4.83E-05	2.10E-17
4	4.5	9.23E-17	-16.04	1.92E-16	4.83E-05	3.81E-17
5	5	8.18E-17	-16.09	1.92E-16	4.83E-05	5.52E-17
6	5.5	7.52E-17	-16.12	1.92E-16	4.83E-05	6.56E-17
7	6	7.20E-17	-16.14	1.92E-16	4.83E-05	6.97E-17
8	6.5	6.94E-17	-16.16	1.92E-16	4.83E-05	6.99E-17
9	7	6.45E-17	-16.19	1.92E-16	4.83E-05	6.60E-17
10	7.5	4.99E-17	-16.30	1.92E-16	4.83E-05	5.17E-17
11	8	2.01E-17	-16.70	1.92E-16	4.83E-05	2.10E-17
12	8.5	3.03E-18	-17.52	1.93E-16	4.83E-05	3.28E-18
13	9	1.69E-19	-18.77	1.92E-16	4.83E-05	2.13E-19
14	9.5	2.83E-21	-20.55	1.92E-16	4.83E-05	6.63E-21
15	10	3.02E-23	-22.52	1.92E-16	4.83E-05	2.20E-22

Note: Results from the Visual Minteq pH sweep for the effluent. Results in mol/L.

Figure 10.

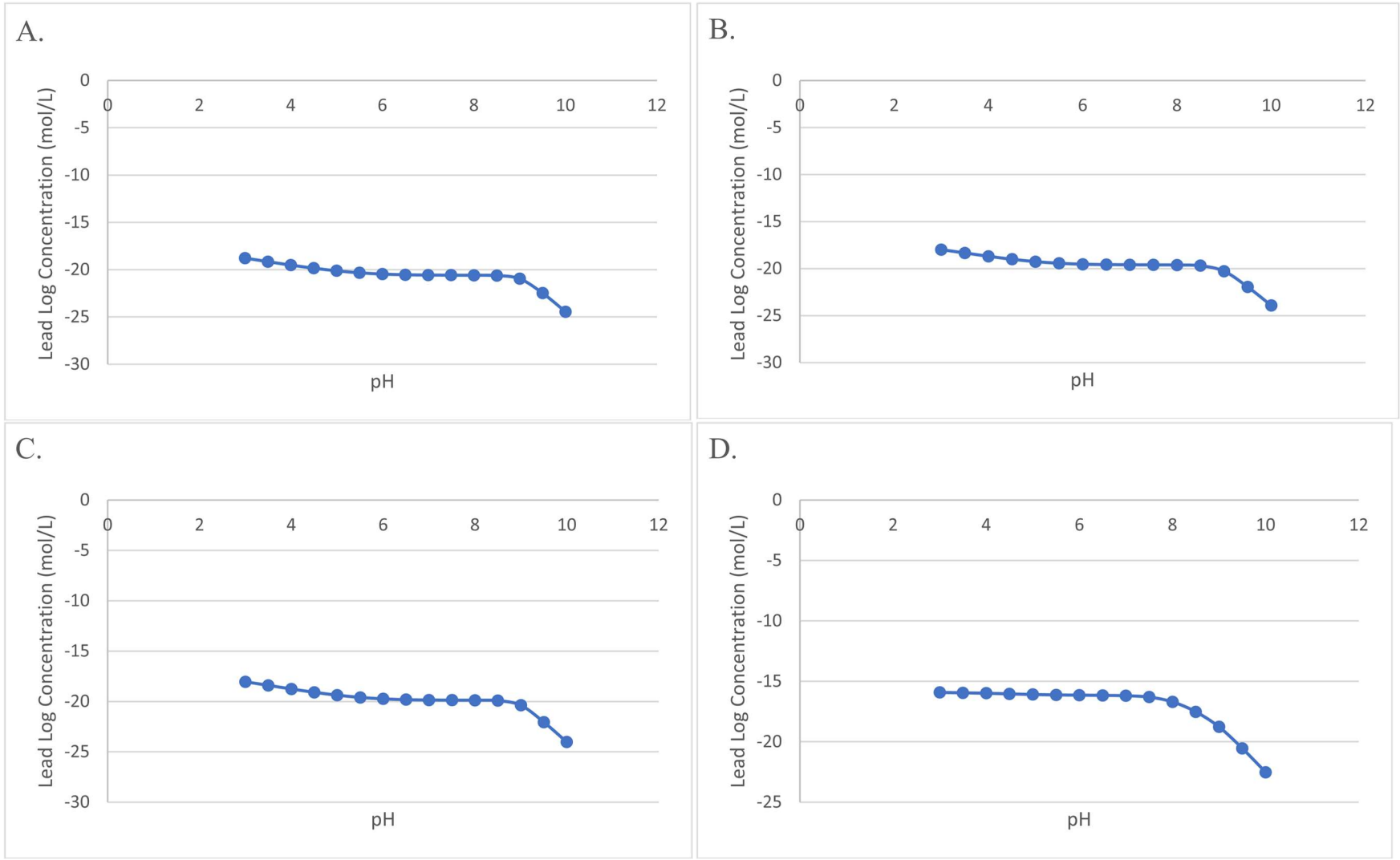
pH vs. Concentration of Lead Graphs



Note: pH vs. concentration graphs for each location. Not in log scale. A= Influent Results, B= Clarifier Results, C= Digester Results, D= Effluent Results

Figure 11.

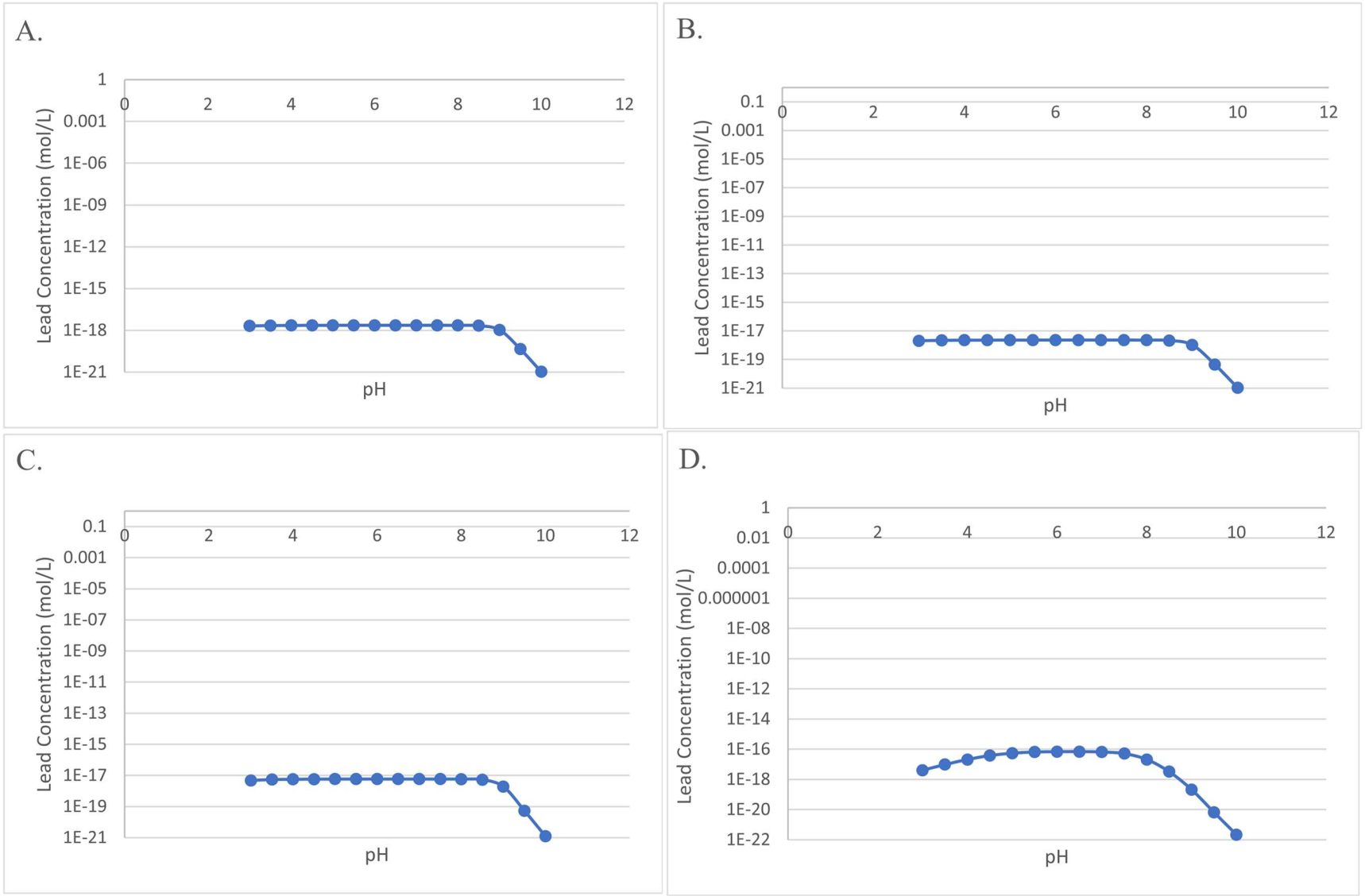
pH vs. Log Concentration Graphs



Note: pH vs. Log Concentration of each location. A= Influent Results, B= Clarifier Results, C=Digester Results, D= Effluent Results.

Figure 12.

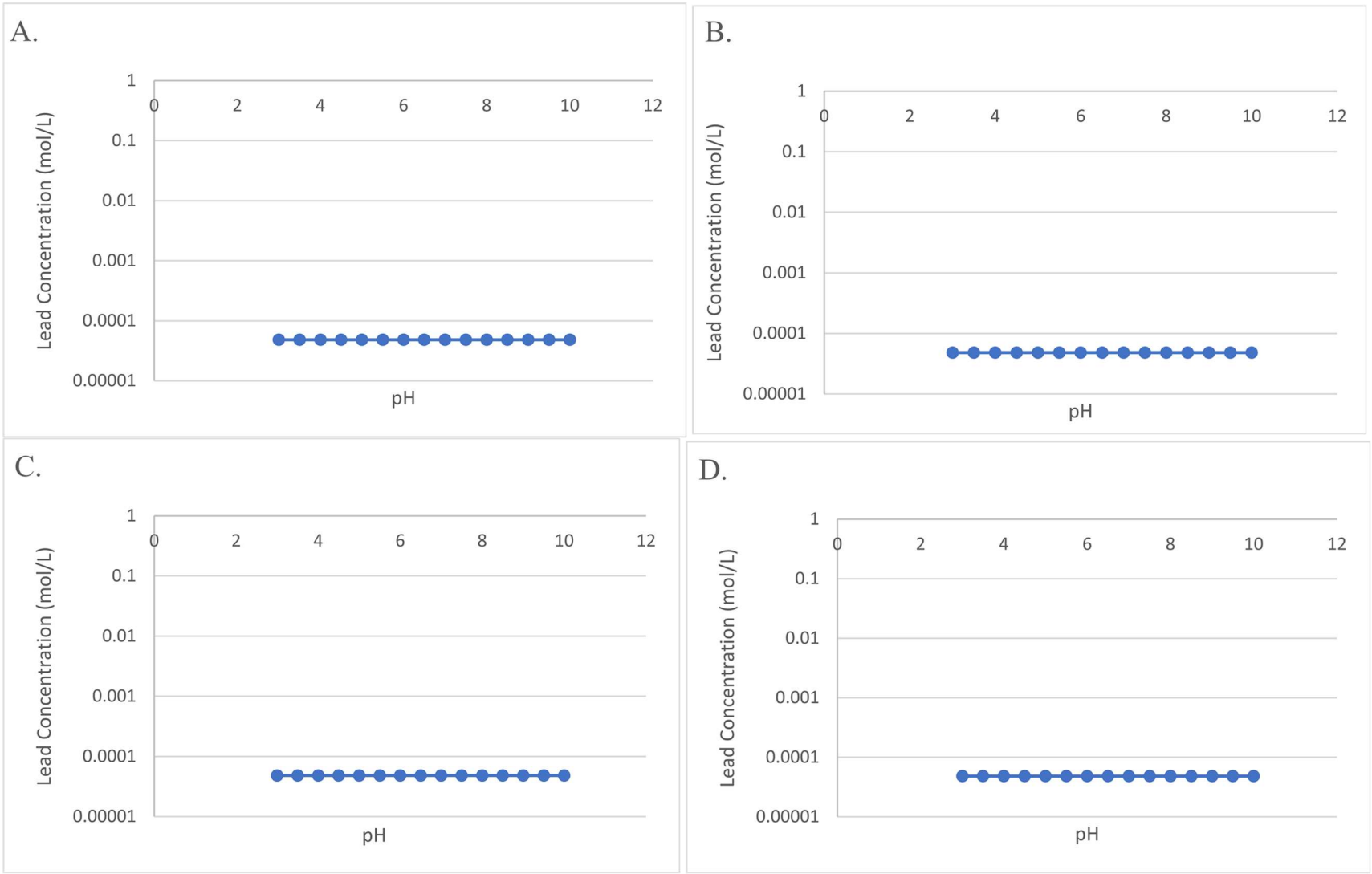
pH vs. Bound to DOC Graphs



Note: pH vs bound to DOC graphs for the various areas. In log scale. A= Influent Results, B= Clarifier Results, C= Digester Results, D= Effluent Results

Figure 13.

pH vs. Total Adsorbed Graphs



Note: pH vs Adsorption to the plastic surface for each area. In log scale. A. Influent Results, B. Clarifier Results, C. Digester Results, D. Effluent Results.

5. ANALYSIS AND DISCUSSION

5.1. Lab Result Analysis

The lab results give an idea of the constituents available in wastewater that could influence adsorption. These tests needed to be completed due to the fact that this suite of constituents had not been previously available, especially for the clarifiers and digesters. These locations from the wastewater treatment plant were used because they were thought to best symbolize the movement of water through the plant. The influent, clarifiers, and effluent show the water movement while the clarifiers to digesters shows the sludge movement. It was interesting to see how high some of the constituent values were entering the plant and how low they were exiting the plant. An average was taken for the clarifiers and digesters since there are two of each of these. Additionally for tests such as pH and BOD the tests were only able to be completed on one digester, so the value was used as a representation of both.

5.1.1. Ammonia Discussion

The ammonia concentrations from Table 8 and the averages that were used for calculations were 32.2 mg/L for the influent, 37.65 mg/L for the clarifiers, 330 mg/L for the digesters, and 0.06 mg/L for the effluent. These values show well how the ammonia values vary as they travel through the plant. It is valid why the values for the influent and clarifiers values are similar due to the fact that in between the influent and clarifiers there is little treatment between these two locations. The digesters have a higher value most likely to the sludge being more concentrated and the high temperatures of the digesters releasing constituents from the sludge. Finally, the effluent is far lower than the other

values due to it being at the end of the treatment processes after several constituents have been removed. The ammonia results had to be converted to ammonium to be inputted into Visual Minteq.

5.1.2. Electroconductivity Discussion

The electroconductivity values from Table 9 and the averages that were used for calculations were 1927 µS/cm for the influent, 2200 µS/cm for the clarifiers, 7295 µS/cm for the digesters, and 1763 µS/cm for the effluent. For electroconductivity the values for the influent, clarifiers, and effluent did not vary extensively. However, the digesters had a much higher average of 7295 µS/cm. This is due to the fact that the sludge from the digesters is more concentrated to allow for a higher electroconductivity. These electroconductivity results were converted to ionic strength for Visual Minteq.

5.1.3. BOD Discussion

The BOD values are shown in Table 10 and the values that were used for calculations were 783 mg BOD/L for the influent, 403 mg BOD/L for the clarifiers, 672 mg BOD/L for the digesters, and 2.04 mg BOD/L for the effluent. The BOD values for the influent were higher than expected. The BOD values did not vary extensively from one area to another except for the effluent. This is due to the organisms that are present are removed during processes between the clarifiers and the effluent. This is logical because the organisms would be removed throughout the WWTP. BOD was not a present constituent in Visual Minteq, so the values had to be converted to DOC.

5.1.4. IC Test Discussion

The IC Test found values for Fluoride, Chloride, Bromide, Nitrate, Nitrite, Sulfate, Phosphate. These values can be found in Table 11. It was interesting to see the values for these constituents due to the fact that there was not an extensive amount of literature to give an idea of what these constituents should be. It is important to note that there were high levels of chloride, sulfate, and phosphate. These values did have an effect on adsorption which can be seen in later sections. Additionally, it is important to note that the digesters lacked values for phosphate and nitrite which can be seen in the lack of species that the digesters have in Table 22. The value for nitrite in the effluent water was high at 16.20 mg NO_3/L but a check of the quality control standards confirmed the results.

5.1.5. pH Test Discussion

The pH values did not largely vary for the various locations. All the pH values were near neutral. The pH values may vary more throughout the plant, but it is compatible that these areas would still have a neutral pH since no chemical processes are taking place. Please see Table 12 for exact pH values.

5.1.6. Alkalinity Test Discussion

The alkalinity for the clarifiers and influent locations was similar averaging around 7 mg/L as $CaCO_3$, which would be consistent with few processes happening before these areas to change the alkalinity. Alkalinity is affected by CO_2 which is why the digesters alkalinity value is so high, but the effluent's alkalinity is so low. The digesters are heated to release more CO_2, but then are enclosed trapping the CO_2 within the

digester. The effluent is aerated, removing CO_2 by releasing it to the open air. Please see Table 13 for alkalinity values.

5.1.7. Additional Constituents Used

Table 27 was adopted from a table in, "Water Works Engineering: Planning, Design, & Operation (Qasim, Motley, Zhu, 2000)." These values we used to account for the metal cations that would be presumed to be found in wastewater. This table was used due to not being capable of completing a lab test for these cations. The surface water values were used due to that being the most median values and the closest to influent wastewater. These cation amounts were first inputted into the influent water conditions and then the non-adsorbed amount from the influent was used as the input information for the clarifiers. Then the non-adsorbed amount for the clarifiers was used for the input for the digesters and effluent water. This was done to simulate what metals would be available at each location. Please see previous Visual Minteq input values section for exact input values.

Table 27.

Cation Concentration Table

	Amount Per Source Water (mg/L)				
Cation:	Rainwater:	Tap Water:	Surface Water:	Ground Water:	Sea Water:
Ca 2+	6	20	20	50	400
Mg 2+	2	3	3	5	1350
Na +	5	20	20	5	10500
K +	n.a.	n.a.	2	2	350
Fe 2+	0.05	0.1	0.1	0.1	0.1

Note: Concentrations of cations present under different conditions as adopted from table 2-1 in " Water Works Engineering: Planning, Design, & Operation (Qasim, Motley, Zhu, 2000)."

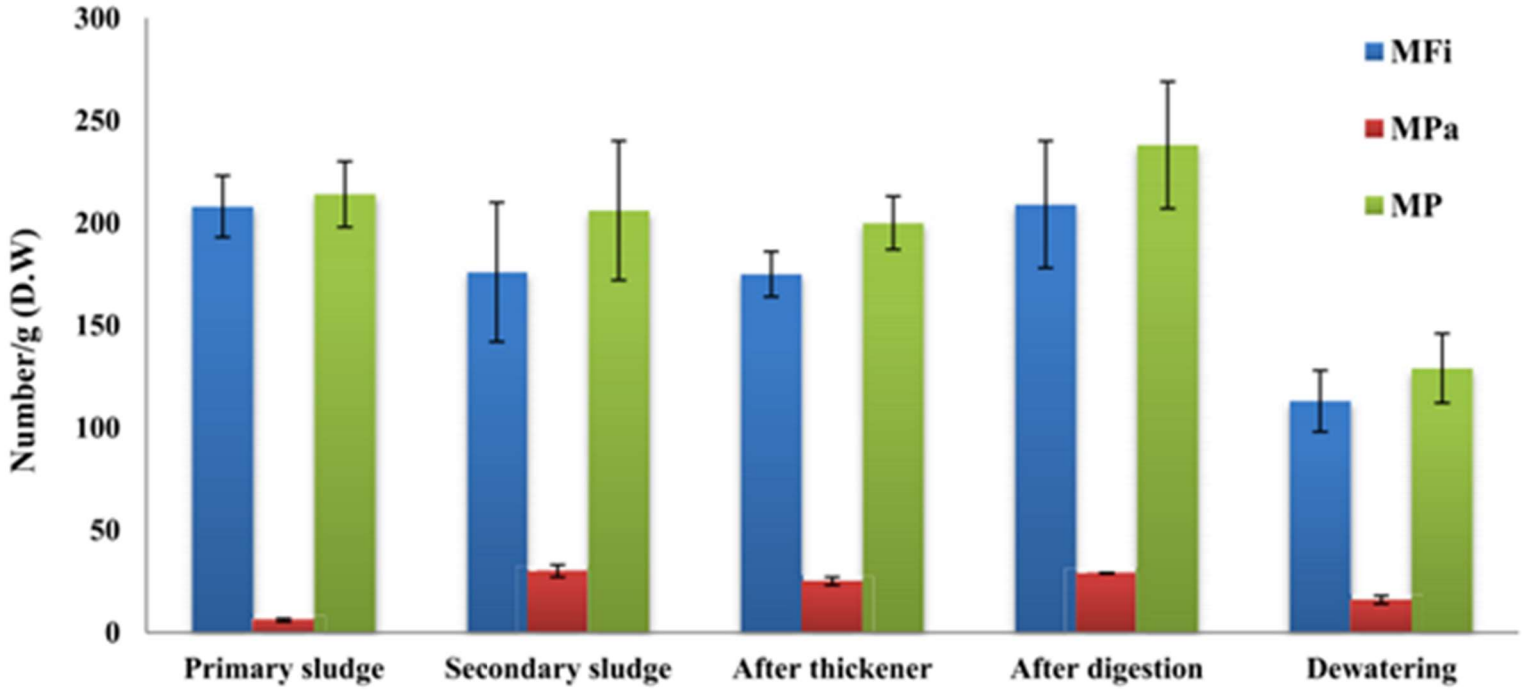
5.2. Visual Minteq Input Values Discussion

These values give an idea of how wastewater changed in composition throughout the plant. These values also show the starting point from which the adsorption that is explained in further sections expands from. As stated in the results there were several calculations that needed to take place in order to be able to use the lab results in Visual Minteq. The ammonia and ionic strength calculations consisted of basic conversions and can be seen in Appendix A. However, the L/S ratio calls for more explanation. The L/S ratio is the liquid to solid ratio. Visual Minteq called for this value when adding the adsorption surface. The L/S ratio in this case is to account for the ratio of microplastics to water, which would allow for the program to account for how much plastic surface was available for adsorption. However, this information is not readily available. We were able to understand how many microplastics were present in the clarifiers and digesters from Petroody et al.'s article, "Transport and accumulation of microplastics through wastewater treatment sludge processes (2021)." The total suspended solids information came from the daily testing completed at a local WWTP and can be found in Appendix B. Figure 14 shows the figure from Petroody et al. that was used to find the microplastic concentration. Webplot was used to find the numerical values of this figure and these values are shown in Table 28. Webplot is an online software that allows for one to find specific values on a graph, where the values are not given. The clarifiers were assumed to be the same as the primary and secondary sludge and an average of these microplastic values was used for calculations. Once these numbers were found the microplastics were assumed to behave in the water like total solids, so a ratio system was used to find the approximate microplastic concentrations of each location. The calculations for this can be

seen in Appendix A. Once the L/S ratios were found it was interesting to see how the ratios increased throughout the plant. The increase would make sense due to the solids being removed leading to there being more liquid than solid present.

Figure 14.

Microplastic Concentration Graph



Note: Amount of microplastic present in wastewater treatment processes as adapted from Petroody et al. (2021).

Abbreviations: MFi= microfibers, MPa= microparticles, MP= microplastic, D.W.= Dry Weight

Table 28.

Microplastic Concentration Table

Treatment System:	MFi:	Error Lower:	Error Higher:	MPa:	Error Lower:	Error Higher:	MP:	Error Lower:	Error Higher:	(number/g (D.W))
Primary Sludge	207.26	192.89	223.03	6.49	6.03	6.03	213.76	197.99	230.45	
Secondary Sludge	175.73	142.35	210.51	30.14	27.36	32.92	206.34	172.49	240.19	
After Thickener	174.81	164.14	186.40	25.04	23.18	27.36	199.85	187.79	212.83	
After Digestion	208.66	178.05	240.65	28.28	29.21	29.21	237.87	207.26	269.40	
Dewatering	113.14	98.30	128.44	16.23	14.37	18.55	128.44	112.67	146.52	

Note: The numerical values from Figure 14 as found by Webplot (Pertroody et al., 2021).

5.3. Percent of Change- Discussion

5.3.1. Influent

After the first run was completed without any additional adsorption surfaces added. This run was to observe how the inputted species interacted and changed on their own. The most notable changes were observed in sulfate, phosphate, and the cation metals. The high percent of decrease that can be seen in Table 18 for these ions can be attributed to the speciation that occurs using sulfate, phosphate, and the cation metals. As these different input ions for species with each other their original concentrations decrease as shown by the high precents of decrease after a Visual Minteq run without any additions. This speciation process is one of the main reasons that the following percent differences were compared to the without additions run instead of the input, so the change to the additions could be seen. Table 22 shows the different species that were created during the Visual Minteq runs to give an idea of how the input ions combine and reduce in concentration.

When DOC was added there was a notable change with Ca^{2+} and Mg^{2+}. Ca^{2+} and Mg^{2+} had percent decreases of 78.7% and 27.2% respectively. This change suggests the Ca^{2+} and Mg^{2+} both attach to DOC at a high rate. When lead and the plastic adsorption surface were added these percent changes remained for Ca^{2+} and Mg^{2+} suggesting that they were not largely affected by the addition of these surfaces. Additionally, the concentrations of DOC did not change when lead and the plastic adsorption surface were added showing that they did not have an effect on bare DOC. Bare DOC is DOC that is not complexed with any other ions, and is referred to bare DOC to distinguish from other compexes or species. However, lead changed drastically between its interactions with

bare DOC and when the plastic adsorption surface was added. If no additional surfaces were present lead would result in a concentration of $2.628*10^{-5}$ mol/L. When both DOC and the plastic adsorption surface were added lead's concentration decreased to $2.679*10^{-21}$ mol/L. When just DOC and just the plastic adsorption surfaces were present lead had concentrations of $6.418*10^{-8}$ and $1.2514*10^{-18}$ mol/L respectively. These are all changes from the original concentration of $4.83*10^{-5}$ mol/L.

5.3.2. Clarifiers

Table 19 shows the results for the changes that took place between the different clarifier Visual Minteq runs. Ca^{2+} and Mg^{2+} behaved vary similarly in the clarifiers as it did in the influent. This further supports the pervious conclusions about the changes in Ca^{2+} and Mg^{2+}. Lead also changed similarly to the influent runs with concentrations of $1.91*10^{-7}$ mol/L for just DOC, $2.533*10^{-20}$ mol/L for DOC and the plastic adsorption surface, and $4.238*10^{-18}$ mol/L for just the plastic adsorption surface. These results further support the idea that heavy metals like lead can bind to bare DOC and adsorb to plastic surfaces.

5.3.3. Digesters

Table 20 shows the results for the percent of change that occurred between the different Visual Minteq runs for the digesters. Ca^{2+} and Mg^{2+} again behaved similarly to how it was described in the influent. Additionally, the lead followed the same patterns as the influent and clarifiers. The values for lead for the various runs are: $1.33359*10^{-7}$ mol/L for just DOC, $1.3827*10^{-20}$ mol/L for DOC and the plastic adsorption surface, and $4.038*10^{-18}$ mol/L for just the plastic adsorption surface.

5.3.4. Effluent

The data for the different effluent runs can be seen in Table 21. The effluent runs behaved differently from the influent, clarifiers, and digesters. There was minimum change for Ca^{2+} and Mg^{2+} when bare DOC was added. However, unlike the previous three areas the DOC amount for the effluent was considerably smaller with only 1.02 mg/L. So, the small change in Ca^{2+} and Mg^{2+} would be contributed to the lack of bare DOC to bind to.

However, the lead still changed similarly to the previous three areas. The values for lead for the various runs are: $1.96*10^{-5}$ mol/L for just DOC, $5.7676*10^{-17}$ mol/L for DOC and the plastic adsorption surface, and $8.348*10^{-17}$ mol/L for just the plastic adsorption surface. These values are slightly different from the previous three areas but that can also be contributed to the small DOC amount.

5.4. Speciation Discussion

Table 22 shows any speciation that may occur according to Visual Minteq. The list of species may seem long but several of these species occur in minute amounts. Additionally Visual Minteq does not allow for precipitation to occur so some of these species may drop out of solution in the real world. However, it is useful to see what species are possible in these conditions. Since the additional species concentrations were so minute, these species were not analyzed further, but could be useful for future work. The grey boxes in Table 22 show the missing species for each location. These species would not be present due to the fact that certain constituents were not found in every area.

Table 22 additionally gives an idea of what species could be contributed to lead. There were 27 lead species present from the Visual Minteq runs. As stated in section 5.3 the speciation plays a large role in what constituents are still available. The lead speciation is important to understand in order to fully understand what is still available for adsorption to microplastics after speciation occurs. Visual Minteq also does not allow for precipitation so some of the species may precipitate and fall out of solution.

5.5. pH Sweep Discussion

It was hypothesized that pH could have a large effect on adsorption. The effect of pH on adsorption was studied in Visual Minteq by completing a pH sweep. A pH sweep is where Visual Minteq runs the constituents' involvement with one another under different pH conditions. Data from Zou et al. (2020) as shown in Figure 6 suggests that pH can influence adsorption. Zou et al. suggests that adsorption increases with pH. However, the data that was found by completing pH sweeps in Visual Minteq suggests that pH does not influence adsorption. Instead, the differences shown in Figure 6 could be attributed to the different species that occur. Figure 13 shows how when the pH changes the adsorption stay the same. This occurred in all four locations as present in Figure 13. When adsorption to the plastic surface was compared to pH in Figure 13 and shown at log scale only a straight line is formed. This shows that there is little affect on adsorption by pH.

Figures 10 and 11 show concentration of lead compared to pH with and without log scale. Both show the concentration of lead decreasing as pH increases. This is due to the speciation of lead changing at higher pH. As the pH increases there are more OH^- ions for lead to bind with, which would cause its concentration to decrease with an

increase in pH. This could lead one to attribute increase adsorption with an increase in pH if one was only measuring the amounts of lead in solution as shown in Figure 6.

The conclusions drawn from Figures 10 and 11 are further supported by Figure 12. Figure 12 shows the concentration of lead that is bound to DOC during a pH sweep at log scale. As pH increases the amount of lead bound to DOC decreases. This again is due to the fact that lead is bonding to more OH- ions as pH increases leaving less lead available to bond to bare DOC. Additionally, this further supports the idea that adsorption is not actually affected by pH, but instead lead falls into different species causing less lead to be present in solution.

6. CONCLUSIONS

6.1. Conclusions on Research

Several final conclusions can be gathered from the research that was completed. Firstly, there was a large amount of knowledge gained on the basic constituents that are present within the plant from the lab tests completed. This knowledge was extremely useful in understanding what species can occur in wastewater and how these species can affect adsorption to a plastic surface. Once the wastewater constituents were identified and the system modeled by Visual Minteq a few major conclusions were drawn from the results.

Firstly, the large percent of decrease in Ca^{2+} and Mg^{2+} when DOC was added suggests they both attach to bare DOC at a high rate. The next conclusion observed was that the concentrations of bare DOC did not change when lead and the plastic adsorption surface were added showing that they did not have an effect on bare DOC. However, lead changed drastically between its interactions with just DOC and when the plastic adsorption surface was added implying that the lead did adsorb to the plastic surface.

The final conclusions that were drawn from the Visual Minteq runs were found during the pH sweeps. It was concluded that pH does not influence adsorption, instead the differences in lead concentration that were present could be attributed to the different species that occur as pH increases. The fact that lead can bind to OH- more as pH increases is shown in the decrease in lead concentration and the decrease in lead binding to bare DOC.

6.2. Future Work

The data that was obtained in this study could be used for a large variety of future work. Firstly, the work on adsorption could be continued to complete an in-lab experiment to compare real world results to those from Visual Minteq. Additionally, more work could be completed to find the actual cation metal amounts that are present in wastewater, and the constituents' study could be completed on more areas of the wastewater treatment plant. Additionally, samples could be taken from more than one plant to gain a more comprehensive idea of what constituents are available. Visual Minteq studies could also be completed on other areas that contribute to microplastic pollution such as landfill leachate. Lastly, the data that was presented in this thesis can be used in further adsorption studies and to better understand microplastic pollution.

6.3. Final Conclusions

Microplastics are an emerging concern within the environment. It is important to understand how adsorption to these microplastics works. This study completed a geochemical modeling analysis on microplastic adsorption with a WWTP using Visual Minteq. This modeling study mainly observed how lead can adsorb to a plastic surface in a WWTP environment and what species are formed form the constituents within a WWTP. It was observed during the study that lead can be affected by both DOC and a plastic adsorption surface but the adsorption to plastic is not effected by DOC. Additionally, it was discovered the pH does not affect adsorption of lead to a plastic surface, but more species occur at a high pH reducing lead's concentration. This data could further be used for future work.

APPENDIX A

Calculations for Ionic Strength:

Equation used (aquion, 2021):

$$Electrical\ Conductivity\ (EC)\ \left(\mu S/_{cm}\right)$$

$$= (6.2 * 10^4)\left(Ionic\ Strength\ (I)\left(mol/_L\right)\right)$$

For Influent:

$$1927\left(\mu S/_{cm}\right) = (6.2 * 10^4)\left(I\left(mol/_L\right)\right)$$

$$I = 0.031\ mol/L$$

For Clarifiers:

$$2200\left(\mu S/_{cm}\right) = (6.2 * 10^4)\left(I\left(mol/_L\right)\right)$$

$$I = 0.035\ mol/L$$

For Digesters:

$$7295\left(\mu S/_{cm}\right) = (6.2 * 10^4)\left(I\left(mol/_L\right)\right)$$

$$I = 0.118\ mol/L$$

For Effluent:

$$1763\left(\mu S/_{cm}\right) = (6.2 * 10^4)\left(I\left(mol/_L\right)\right)$$

$$I = 0.028\ mol/L$$

Ammonium Calculations

Conversion used:

$$NH_4 = \frac{NH_3}{0.9441}$$

For Influent:

$$NH_4 = \frac{32.2}{0.9441} = 34.1 \ {}^{mgNH_4}/_{L}$$

For Clarifiers:

$$NH_4 = \frac{37.65}{0.9441} = 39.88 \ {}^{mgNH_4}/_{L}$$

For Digesters:

$$NH_4 = \frac{330}{0.9441} = 349.5 \ {}^{mgNH_4}/_{L}$$

For Effluent:

$$NH_4 = \frac{0.06}{0.9441} = 0.063 \ {}^{mgNH_4}/_{L}$$

L/S Ratio Information and Calculations

Information per area:

- Influent:
    - TSS= 219.62 mg/L
- Clarifiers/Settling tanks:
    - TSS= 65.33 mg/L
    - Removal efficiency of MPs= 40.7-91.7% (Golwala et al., 2021)
    - Microplastic Concentration= 210.05 #MPs/g (Petroody, et al., 2021)
    - Microplastic Concentration= 321*10^6 /d (Petroody et al., 2021)
- Digesters:
    - Microplastic Concentration= 237.86 #MPs/g (Petroody et al., 2021)
    - Microplastic Concentration= 601 * 10^6 /d (Petroody et al., 2021)
- Effluent:
    - TSS= 2.56 mg/L

Calculations to Determining Microplastics per Area:

$$\frac{65.33\ mg}{L} * \frac{g}{1000mg} = \frac{0.06533g}{L} \rightarrow \frac{0.06533g}{L} * \frac{210.05\ \#MPs}{g} = 13.72\ {}^{\#MPs}/_{L}$$

$$\%\ Removal = \frac{(in - out)}{in} * 100\%$$

From influent to clarifiers:

$$\frac{219.62 - 65.33}{219.62} * 100\% = 70.2\%$$

From clarifiers to effluent:

$$\frac{65.33 - 2.56}{65.33} * 100\% = 96.1\%$$

Microplastics in influent:

$$x - 0.702x = 1372$$

$$x = 46.04 \ {}^{\#MPs}/_{L}$$

(x= amount of microplastics in influent)

Microplastics in effluent:

$$13.72 * 0.961 = 13.17$$

$$13.72 - 13.17 = 0.55 \ {}^{\#MPs}/_{L}$$

Microplastics in digesters:

$$\frac{210.05 - 237.86}{210.05} * 100\% = -13.2\%$$

$$13.72 * 0.132 = 4.19 + 13.72 = 17.92 \ {}^{\#MPs}/_{L}$$

L/S Ratio Calculation:

$$\frac{L}{S}ratio = \frac{1}{\left(\#MPs/_{L}\right) * \left(\frac{4}{3}\pi(0.5\ cm)^{3}\ \left(\frac{Volume}{\#MPs}\right)\right) * 1.389\ {}^{g}/_{cm^{3}} * \frac{1kg}{1000g}}$$

L/S Ratios:

Influent:

$$\frac{1}{\left(46.04\ \#MPs/_{L}\right) * \left(\frac{4}{3}\pi(0.5\ cm)^{3}\right) * 1.389\ {}^{g}/_{cm^{3}} * \frac{1kg}{1000g}} = 30.06\frac{L}{kg}$$

Clarifiers:

$$\frac{1}{\left(13.72\ \#MPs/_{L}\right) * \left(\frac{4}{3}\pi(0.5\ cm)^{3}\right) * 1.389\ {}^{g}/_{cm^{3}} * \frac{1kg}{1000g}} = 100.87\frac{L}{kg}$$

Digesters:

$$\frac{1}{\left(17.92\ \#MPs/_{L}\right) * \left(\frac{4}{3}\pi(0.5\ cm)^{3}\right) * 1.389\ {}^{g}/_{cm^{3}} * \frac{1kg}{1000g}} = 77.23\frac{L}{kg}$$

Effluent:

$$\frac{1}{\left(0.55\ \#MPs/_{L}\right) * \left(\frac{4}{3}\pi(0.5\ cm)^{3}\right) * 1.389\ {}^{g}/_{cm^{3}} * \frac{1kg}{1000g}} = 22516.28\frac{L}{kg}$$

APPENDIX B

Solids information for L/S ratio:

Total Suspended Solids of WWTP (mg/L)								
DATE	INF	PC	EFF	L6	R6	RAS-1	RAS-2	RAS-3
8/31/2021				1340	1290	2500	2540	2420
8/30/2021	248.00	64.00	2.80	1320	1310	2600	2770	2380
8/27/2021	244.00		1.60	1480	1470	2320	2200	2200
8/26/2021				1260	1230	2500	2560	2470
8/25/2021	235.00	60.00	1.20	1320	1360	2620	2420	2770
8/24/2021				1290	1290	2540	2510	2350
8/23/2021	296.00	90.00	2.00	1250	1260	2440	2360	2610
8/20/2021	218.00		1.00	1290	1340	2590	2610	2610
8/19/2021				1250	1290	2540	1890	2130
8/18/2021	260.00	52.00	2.20	1280	1290	2280	2130	2290
8/17/2021				1270	1190	1860.00	1780	2030
8/16/2021	222.00	54.00	7.00	1210	1230	2010	2060	2180
8/13/2021	226.00		2.60	1280	1270	2130	1650	2010
8/12/2021				1290	1210	2060	2120	2410
8/11/2021	132.00	74.00	2.30	1250	1170	1920	1920	1930
8/10/2021				1050	1140	2050	1960	2260
8/9/2021	192.00	50.00	2.40	1370	1270	2200	2300	2420
8/6/2021	130.00		3.00	1340	1330	2440	2400	2310
8/5/2021				1410	1280	2430	2310	2280
8/4/2021	258.00	74.00	3.00	1360	1370	2480	2030	2290
8/3/2021				1200	1230	2360	2150	2310
8/2/2021	194.00	70.00	2.20	1190	1200	2400	1970	2230
Average:	219.62	65.33	2.56	1286.36	1273.64	2330.45	2210.91	2313.18

- INF= Influent
- PC= Primary Clarifier
- EFF: Effluent
- FC: Final Clarifier
- L6: Left Aeration Basin 6
- R6: Right Aeration Basin 6
- RAS 1: Recycled Activated Sludge 1
- RAS 2: Recycled Activated Sludge 2
- RAS 3: Recycled Activated Sludge 3

APPENDIX C

Example Visual Minteq run (Influent Raw Data): **All results in mol/L**

Visual Minteq run without additions:

	Concentration	Activity	Log activity
Br-1	0.000018272	0.00001549	-4.81
Ca(NH3)2+2	4.3633E-14	2.2537E-14	-13.647
Ca+2	0.00043015	0.00022219	-3.653
CaCl+	5.7163E-06	4.8461E-06	-5.315
CaCO3 (aq)	1.5629E-08	1.5741E-08	-7.803
CaF+	3.0904E-07	2.6199E-07	-6.582
CaH2PO4+	1.1411E-06	9.674E-07	-6.014
CaHCO3+	2.4142E-07	2.0466E-07	-6.689
CaHPO4 (aq)	0.00001565	0.000015762	-4.802
CaNH3+2	7.7932E-09	4.0254E-09	-8.395
CaOH+	6.6219E-10	5.6138E-10	-9.251
CaPO4-	6.2278E-07	5.2797E-07	-6.277
CaSO4 (aq)	0.000045175	0.000045499	-4.342
Cl-1	0.010242	0.0086831	-2.061
CO3-2	8.2648E-08	4.269E-08	-7.37
F-1	0.00010076	0.000085422	-4.068
Fe(NH3)2+2	2.7167E-14	1.4033E-14	-13.853
Fe(NH3)3+2	8.3587E-19	4.3175E-19	-18.365
Fe(NH3)4+2	1.0971E-23	5.6667E-24	-23.247
Fe(OH)2 (aq)	3.1112E-13	3.1335E-13	-12.504
Fe(OH)3-	1.4801E-16	1.2548E-16	-15.901
Fe+2	1.1963E-06	6.1794E-07	-6.209
FeCl+	3.9934E-09	3.3855E-09	-8.47
FeF+	1.0098E-09	8.5608E-10	-9.067
FeH2PO4+	7.105E-08	6.0233E-08	-7.22
FeHCO3+	6.6374E-10	5.6269E-10	-9.25
FeHPO4 (aq)	3.7908E-07	3.818E-07	-6.418
FeNH3+2	3.4352E-10	1.7744E-10	-9.751
FeOH+	3.6746E-09	3.1152E-09	-8.507
FeSO4 (aq)	1.3463E-07	1.3559E-07	-6.868
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00022941	0.00019449	-3.711

	Concentration	Activity	Log activity
H3PO4	2.1567E-09	2.1722E-09	-8.663
HCO3-	0.00008532	0.000072331	-4.141
HF (aq)	1.0197E-08	1.027E-08	-7.988
HF2-	4.1197E-12	3.4925E-12	-11.457
HPO4-2	0.00030047	0.0001552	-3.809
HSO4-	8.1849E-09	6.9388E-09	-8.159
K+1	0.000050566	0.000042868	-4.368
K2HPO4 (aq)	3.7762E-12	3.8032E-12	-11.42
K2PO4-	3.25E-16	2.7552E-16	-15.56
KCl (aq)	1.8523E-07	1.8655E-07	-6.729
KF (aq)	1.6619E-09	1.6738E-09	-8.776
KH2PO4 (aq)	1.6517E-08	1.6635E-08	-7.779
KHPO4-	5.9532E-08	5.0469E-08	-7.297
KOH (aq)	9.3664E-12	9.4335E-12	-11.025
KPO4-2	1.8405E-12	9.5065E-13	-12.022
KSO4-	3.1999E-07	2.7128E-07	-6.567
Mg(NH3)2+2	2.1543E-14	1.1127E-14	-13.954
Mg+2	0.00010644	0.000054979	-4.26
Mg2CO3+2	9.7193E-13	5.0203E-13	-12.299
MgCl+	2.2418E-06	1.9005E-06	-5.721
MgCO3 (aq)	1.9383E-09	1.9522E-09	-8.709
MgF+	4.4004E-07	3.7305E-07	-6.428
MgHCO3+	4.8112E-08	4.0787E-08	-7.389
MgHPO4 (aq)	5.3455E-06	5.3838E-06	-5.269
MgOH+	3.1223E-09	2.6469E-09	-8.577
MgPO4-	2.4089E-09	2.0422E-09	-8.69
MgSO4 (aq)	8.8794E-06	0.000008943	-5.049
Na+1	0.00086063	0.00072961	-3.137
Na2HPO4 (aq)	7.2273E-10	7.279E-10	-9.138
Na2PO4-	2.0128E-13	1.7064E-13	-12.768
NaCl (aq)	3.1526E-06	3.1752E-06	-5.498
NaCO3-	6.8414E-10	5.7999E-10	-9.237
NaF (aq)	6.4798E-08	6.5262E-08	-7.185
NaH2PO4 (aq)	2.8111E-07	2.8313E-07	-6.548
NaHCO3 (aq)	2.6261E-08	2.645E-08	-7.578
NaHPO4-	1.5693E-06	1.3304E-06	-5.876
NaOH (aq)	1.1549E-10	1.1631E-10	-9.934
NaPO4-2	3.1325E-11	1.618E-11	-10.791
NaSO4-	4.2277E-06	3.5841E-06	-5.446
NH3 (aq)	0.000011246	0.000011326	-4.946
NH4+1	0.0018613	0.001578	-2.802
NH4SO4-	0.000017828	0.000015114	-4.821

	Concentration	Activity	Log activity
OH-	1.4937E-07	1.2663E-07	-6.897
PO4-3	3.6428E-09	8.2393E-10	-9.084
SO4-2	0.0017306	0.00089389	-3.049

Visual Minteq run with DOC added:

	Concentration	Activity	Log activity
Br-1	0.000018272	0.00001549	-4.81
Ca DOM1	0.00039262	0.00035324	-3.452
Ca(NH3)2+2	9.2746E-15	4.7906E-15	-14.32
Ca+2	0.000091471	0.000047247	-4.326
CaCl+	1.2162E-06	0.000001031	-5.987
CaCO3 (aq)	3.3236E-09	3.3474E-09	-8.475
CaF+	6.5951E-08	5.5911E-08	-7.253
CaH2PO4+	2.4947E-07	2.1149E-07	-6.675
CaHCO3+	5.1337E-08	4.3521E-08	-7.361
CaHPO4 (aq)	3.4213E-06	3.4458E-06	-5.463
CaNH3+2	1.6569E-09	8.5582E-10	-9.068
CaOH+	1.4081E-10	1.1938E-10	-9.923
CaPO4-	1.3615E-07	1.1542E-07	-6.938
CaSO4 (aq)	9.8122E-06	9.8825E-06	-5.005
Cl-1	0.010247	0.0086873	-2.061
CO3-2	8.2648E-08	4.269E-08	-7.37
DOC (Gaussian DOM)	0.032625	0.032859	-1.483
DOM1	0.0023756	0.00065078	-3.187
F-1	0.00010112	0.000085727	-4.067
Fe(NH3)2+2	2.692E-14	1.3905E-14	-13.857
Fe(NH3)3+2	8.2809E-19	4.2773E-19	-18.369
Fe(NH3)4+2	1.0866E-23	5.6128E-24	-23.251
Fe(OH)2 (aq)	3.0842E-13	3.1063E-13	-12.508
Fe(OH)3-	1.4673E-16	1.2439E-16	-15.905
Fe+2	1.1859E-06	6.1257E-07	-6.213
FeCl+	3.9607E-09	3.3577E-09	-8.474
FeF+	1.0046E-09	8.5167E-10	-9.07
FeH2PO4+	7.2409E-08	6.1386E-08	-7.212
FeHCO3+	6.5797E-10	5.578E-10	-9.254
FeHPO4 (aq)	3.8634E-07	3.8911E-07	-6.41
FeNH3+2	3.4046E-10	1.7586E-10	-9.755
FeOH+	3.6427E-09	3.0881E-09	-8.51
FeSO4 (aq)	1.3632E-07	1.3729E-07	-6.862
H DOM1	9.4642E-06	5.5423E-06	-5.256

	Concentration	Activity	Log activity
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00023585	0.00019995	-3.699
H3PO4	2.2172E-09	2.2331E-09	-8.651
HCO3-	0.00008532	0.000072331	-4.141
HF (aq)	1.0233E-08	1.0307E-08	-7.987
HF2-	4.1492E-12	3.5175E-12	-11.454
HPO4-2	0.0003089	0.00015956	-3.797
HSO4-	8.3602E-09	7.0875E-09	-8.15
K+1	0.000050556	0.00004286	-4.368
K2HPO4 (aq)	3.8807E-12	3.9085E-12	-11.408
K2PO4-	3.3399E-16	2.8315E-16	-15.548
KCl (aq)	1.8528E-07	1.8661E-07	-6.729
KF (aq)	1.6675E-09	1.6795E-09	-8.775
KH2PO4 (aq)	1.6977E-08	1.7099E-08	-7.767
KHPO4-	6.1191E-08	5.1875E-08	-7.285
KOH (aq)	9.3646E-12	9.4317E-12	-11.025
KPO4-2	1.8918E-12	9.7715E-13	-12.01
KSO4-	3.2679E-07	2.7704E-07	-6.557
Mg DOM1	0.000033274	0.000029937	-4.524
Mg(NH3)2+2	1.5683E-14	8.1008E-15	-14.091
Mg+2	0.000077522	0.000040042	-4.397
Mg2CO3+2	5.1554E-13	2.6629E-13	-12.575
MgCl+	1.6335E-06	1.3848E-06	-5.859
MgCO3 (aq)	1.4117E-09	1.4218E-09	-8.847
MgF+	3.2163E-07	2.7267E-07	-6.564
MgHCO3+	3.504E-08	2.9706E-08	-7.527
MgHPO4 (aq)	4.0025E-06	4.0311E-06	-5.395
MgOH+	2.274E-09	1.9278E-09	-8.715
MgPO4-	1.8037E-09	1.5291E-09	-8.816
MgSO4 (aq)	6.6055E-06	6.6528E-06	-5.177
Na+1	0.00086048	0.00072948	-3.137
Na2HPO4 (aq)	7.4275E-10	7.4807E-10	-9.126
Na2PO4-	2.0686E-13	1.7537E-13	-12.756
NaCl (aq)	3.1536E-06	3.1762E-06	-5.498
NaCO3-	6.8402E-10	5.7988E-10	-9.237
NaF (aq)	6.5018E-08	6.5484E-08	-7.184
NaH2PO4 (aq)	2.8895E-07	2.9102E-07	-6.536
NaHCO3 (aq)	2.6257E-08	2.6445E-08	-7.578
NaHPO4-	1.6131E-06	1.3675E-06	-5.864
NaOH (aq)	1.1547E-10	1.1629E-10	-9.934
NaPO4-2	3.2198E-11	1.6631E-11	-10.779

	Concentration	Activity	Log activity
NaSO4-	4.3175E-06	3.6602E-06	-5.436
NH3 (aq)	0.000011244	0.000011324	-4.946
NH4+1	0.0018609	0.0015776	-2.802
NH4SO4-	0.000018206	0.000015435	-4.812
OH-	1.4937E-07	1.2663E-07	-6.897
PO4-3	3.745E-09	8.4706E-10	-9.072
SO4-2	0.0017677	0.00091304	-3.04

Visual Minteq run with DOC and 10mg of lead added:

	Concentration	Activity	Log activity
Br-1	0.000018272	0.00001549	-4.81
Ca DOM1	0.00038111	0.00034289	-3.465
Ca(NH3)2+2	1.0278E-14	5.3087E-15	-14.275
Ca+2	0.00010136	0.000052356	-4.281
CaCl+	1.3476E-06	1.1425E-06	-5.942
CaCO3 (aq)	3.6829E-09	3.7093E-09	-8.431
CaF+	7.3069E-08	6.1945E-08	-7.208
CaH2PO4+	2.7617E-07	2.3412E-07	-6.631
CaHCO3+	5.6888E-08	4.8228E-08	-7.317
CaHPO4 (aq)	3.7874E-06	3.8146E-06	-5.419
CaNH3+2	1.8361E-09	9.4837E-10	-9.023
CaOH+	1.5604E-10	1.3229E-10	-9.878
CaPO4-	1.5072E-07	1.2777E-07	-6.894
CaSO4 (aq)	0.000010865	0.000010943	-4.961
Cl-1	0.010247	0.0086872	-2.061
CO3-2	8.2648E-08	4.269E-08	-7.37
DOC (Gaussian DOM)	0.032625	0.032859	-1.483
DOM1	0.0023432	0.00064191	-3.193
F-1	0.0001011	0.000085711	-4.067
Fe(NH3)2+2	2.6929E-14	1.3909E-14	-13.857
Fe(NH3)3+2	8.2837E-19	4.2787E-19	-18.369
Fe(NH3)4+2	1.087E-23	5.6147E-24	-23.251
Fe(OH)2 (aq)	3.0851E-13	3.1072E-13	-12.508
Fe(OH)3-	1.4677E-16	1.2443E-16	-15.905
Fe+2	1.1863E-06	6.1276E-07	-6.213
FeCl+	3.9618E-09	3.3587E-09	-8.474
FeF+	1.0047E-09	8.5178E-10	-9.07
FeH2PO4+	7.2359E-08	6.1343E-08	-7.212
FeHCO3+	6.5818E-10	5.5798E-10	-9.253
FeHPO4 (aq)	3.8607E-07	3.8884E-07	-6.41

	Concentration	Activity	Log activity
FeNH3+2	3.4057E-10	1.7591E-10	-9.755
FeOH+	3.6438E-09	3.0891E-09	-8.51
FeSO4 (aq)	1.3626E-07	1.3724E-07	-6.863
H DOM1	8.2904E-06	4.8549E-06	-5.314
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00023561	0.00019975	-3.7
H3PO4	2.215E-09	2.2309E-09	-8.652
HCO3-	0.00008532	0.000072331	-4.141
HF (aq)	1.0231E-08	1.0305E-08	-7.987
HF2-	4.1477E-12	3.5162E-12	-11.454
HPO4-2	0.00030859	0.0001594	-3.798
HSO4-	8.3542E-09	7.0823E-09	-8.15
K+1	0.000050557	0.00004286	-4.368
K2HPO4 (aq)	3.8769E-12	3.9046E-12	-11.408
K2PO4-	3.3366E-16	2.8287E-16	-15.548
KCl (aq)	1.8528E-07	1.8661E-07	-6.729
KF (aq)	1.6672E-09	1.6792E-09	-8.775
KH2PO4 (aq)	1.696E-08	1.7082E-08	-7.767
KHPO4-	6.113E-08	5.1824E-08	-7.285
KOH (aq)	9.3647E-12	9.4318E-12	-11.025
KPO4-2	1.8899E-12	9.7618E-13	-12.01
KSO4-	3.2655E-07	2.7684E-07	-6.558
Mg DOM1	0.000030158	0.000027133	-4.567
Mg(NH3)2+2	1.6227E-14	8.3817E-15	-14.077
Mg+2	0.000080209	0.00004143	-4.383
Mg2CO3+2	5.5191E-13	2.8508E-13	-12.545
MgCl+	1.6901E-06	1.4328E-06	-5.844
MgCO3 (aq)	1.4606E-09	1.4711E-09	-8.832
MgF+	3.3272E-07	2.8207E-07	-6.55
MgHCO3+	3.6255E-08	3.0736E-08	-7.512
MgHPO4 (aq)	4.1371E-06	4.1667E-06	-5.38
MgOH+	2.3528E-09	1.9946E-09	-8.7
MgPO4-	1.8643E-09	1.5805E-09	-8.801
MgSO4 (aq)	6.8296E-06	6.8785E-06	-5.163
Na+1	0.00086049	0.00072949	-3.137
Na2HPO4 (aq)	7.4202E-10	7.4733E-10	-9.126
Na2PO4-	2.0665E-13	1.7519E-13	-12.756
NaCl (aq)	3.1535E-06	3.1761E-06	-5.498
NaCO3-	6.8402E-10	5.7989E-10	-9.237
NaF (aq)	6.5007E-08	6.5472E-08	-7.184
NaH2PO4 (aq)	2.8866E-07	2.9073E-07	-6.537

	Concentration	Activity	Log activity
NaHCO3 (aq)	2.6257E-08	2.6445E-08	-7.578
NaHPO4-	1.6115E-06	1.3661E-06	-5.865
NaOH (aq)	1.1547E-10	1.1629E-10	-9.934
NaPO4-2	3.2166E-11	1.6615E-11	-10.78
NaSO4-	4.3144E-06	3.6576E-06	-5.437
NH3 (aq)	0.000011244	0.000011324	-4.946
NH4+1	0.001861	0.0015776	-2.802
NH4SO4-	0.000018193	0.000015424	-4.812
OH-	1.4937E-07	1.2663E-07	-6.897
Pb DOM1	0.000048151	0.000043321	-4.363
Pb(CO3)2-2	1.0188E-12	5.2623E-13	-12.279
Pb(OH)2 (aq)	4.1928E-11	4.2229E-11	-10.374
Pb(OH)3-	6.3078E-15	5.3475E-15	-14.272
Pb(SO4)2-2	1.5768E-10	8.1447E-11	-10.089
Pb+2	6.4184E-08	3.3153E-08	-7.479
Pb2OH+3	2.4498E-14	5.541E-15	-14.256
Pb3(OH)4+2	2.2837E-18	1.1796E-18	-17.928
Pb4(OH)4+4	5.4939E-22	3.9107E-23	-22.408
PbBr+	3.036E-11	2.5738E-11	-10.589
PbBr2 (aq)	3.1444E-15	3.1669E-15	-14.499
PbBr3-	1.4874E-19	1.2609E-19	-18.899
PbCl+	1.2335E-08	1.0457E-08	-7.981
PbCl2 (aq)	1.9732E-10	1.9874E-10	-9.702
PbCl3-	1.6176E-12	1.3714E-12	-11.863
PbCl4-2	8.7688E-15	4.5293E-15	-14.344
PbCO3 (aq)	4.7615E-09	4.7957E-09	-8.319
PbF+	4.7346E-10	4.0138E-10	-9.396
PbF2 (aq)	4.2024E-13	4.2325E-13	-12.373
PbH2PO4+	2.4702E-10	2.0941E-10	-9.679
PbHCO3+	2.252E-09	1.9092E-09	-8.719
PbHPO4 (aq)	6.6054E-09	6.6527E-09	-8.177
PbOH+	1.2439E-08	1.0545E-08	-7.977
PbSO4 (aq)	1.471E-08	1.4815E-08	-7.829
PO4-3	3.7413E-09	8.4621E-10	-9.073
SO4-2	0.0017664	0.00091238	-3.04

Visual Minteq run with DOC, 10mg of lead, and plastic adsorption surface added:

	Concentration	Activity	Log activity
ads-Pb-PVC	0.000048268	0.000048268	-4.316
Br-1	0.000018272	0.00001549	-4.81
Ca DOM1	0.00039259	0.00035321	-3.452
Ca(NH3)2+2	9.2729E-15	4.7897E-15	-14.32
Ca+2	0.000091455	0.000047239	-4.326
CaCl+	1.2159E-06	1.0308E-06	-5.987
CaCO3 (aq)	3.323E-09	3.3468E-09	-8.475
CaF+	6.5939E-08	5.5901E-08	-7.253
CaH2PO4+	2.4942E-07	2.1145E-07	-6.675
CaHCO3+	5.1328E-08	4.3514E-08	-7.361
CaHPO4 (aq)	3.4207E-06	3.4452E-06	-5.463
CaNH3+2	1.6566E-09	8.5567E-10	-9.068
CaOH+	1.4079E-10	1.1936E-10	-9.923
CaPO4-	1.3613E-07	1.154E-07	-6.938
CaSO4 (aq)	9.8105E-06	9.8808E-06	-5.005
Cl-1	0.010247	0.0086873	-2.061
CO3-2	8.2648E-08	4.269E-08	-7.37
DOC (Gaussian DOM)	0.032625	0.032859	-1.483
DOM1	0.0023756	0.00065079	-3.187
F-1	0.00010112	0.000085727	-4.067
Fe(NH3)2+2	2.692E-14	1.3905E-14	-13.857
Fe(NH3)3+2	8.2809E-19	4.2773E-19	-18.369
Fe(NH3)4+2	1.0866E-23	5.6128E-24	-23.251
Fe(OH)2 (aq)	3.0842E-13	3.1063E-13	-12.508
Fe(OH)3-	1.4673E-16	1.2439E-16	-15.905
Fe+2	1.1859E-06	6.1257E-07	-6.213
FeCl+	3.9607E-09	3.3577E-09	-8.474
FeF+	1.0046E-09	8.5167E-10	-9.07
FeH2PO4+	7.2409E-08	6.1386E-08	-7.212
FeHCO3+	6.5797E-10	5.578E-10	-9.254
FeHPO4 (aq)	3.8634E-07	3.8911E-07	-6.41
FeNH3+2	3.4046E-10	1.7586E-10	-9.755
FeOH+	3.6427E-09	3.0881E-09	-8.51
FeSO4 (aq)	1.3632E-07	1.3729E-07	-6.862
H DOM1	9.4652E-06	5.5429E-06	-5.256
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00023585	0.00019995	-3.699
H3PO4	2.2172E-09	2.2331E-09	-8.651
HCO3-	0.00008532	0.000072331	-4.141

	Concentration	Activity	Log activity
HF (aq)	1.0233E-08	1.0307E-08	-7.987
HF2-	4.1492E-12	3.5175E-12	-11.454
HPO4-2	0.0003089	0.00015956	-3.797
HSO4-	8.3602E-09	7.0875E-09	-8.15
K+1	0.000050556	0.00004286	-4.368
K2HPO4 (aq)	3.8807E-12	3.9085E-12	-11.408
K2PO4-	3.3399E-16	2.8315E-16	-15.548
KCl (aq)	1.8528E-07	1.8661E-07	-6.729
KF (aq)	1.6675E-09	1.6795E-09	-8.775
KH2PO4 (aq)	1.6977E-08	1.7099E-08	-7.767
KHPO4-	6.1191E-08	5.1875E-08	-7.285
KOH (aq)	9.3646E-12	9.4317E-12	-11.025
KPO4-2	1.8918E-12	9.7715E-13	-12.01
KSO4-	3.2679E-07	2.7704E-07	-6.557
Mg DOM1	0.000033276	0.000029938	-4.524
Mg(NH3)2+2	1.5682E-14	8.1003E-15	-14.092
Mg+2	0.000077517	0.00004004	-4.398
Mg2CO3+2	5.1548E-13	2.6626E-13	-12.575
MgCl+	1.6334E-06	1.3848E-06	-5.859
MgCO3 (aq)	1.4116E-09	1.4217E-09	-8.847
MgF+	3.2161E-07	2.7265E-07	-6.564
MgHCO3+	3.5038E-08	2.9704E-08	-7.527
MgHPO4 (aq)	4.0022E-06	4.0309E-06	-5.395
MgOH+	2.2738E-09	1.9277E-09	-8.715
MgPO4-	1.8036E-09	1.529E-09	-8.816
MgSO4 (aq)	6.6051E-06	6.6524E-06	-5.177
Na+1	0.00086048	0.00072948	-3.137
Na2HPO4 (aq)	7.4275E-10	7.4807E-10	-9.126
Na2PO4-	2.0686E-13	1.7537E-13	-12.756
NaCl (aq)	3.1536E-06	3.1762E-06	-5.498
NaCO3-	6.8402E-10	5.7988E-10	-9.237
NaF (aq)	6.5018E-08	6.5484E-08	-7.184
NaH2PO4 (aq)	2.8895E-07	2.9102E-07	-6.536
NaHCO3 (aq)	2.6257E-08	2.6445E-08	-7.578
NaHPO4-	1.6131E-06	1.3675E-06	-5.864
NaOH (aq)	1.1547E-10	1.1629E-10	-9.934
NaPO4-2	3.2199E-11	1.6631E-11	-10.779
NaSO4-	4.3175E-06	3.6602E-06	-5.436
NH3 (aq)	0.000011244	0.000011324	-4.946
NH4+1	0.0018609	0.0015776	-2.802
NH4SO4-	0.000018206	0.000015435	-4.812
OH-	1.4937E-07	1.2663E-07	-6.897

	Concentration	Activity	Log activity
Pb DOM1	2.2946E-18	2.0644E-18	-17.685
Pb(CO3)2-2	4.2523E-26	2.1964E-26	-25.658
Pb(OH)2 (aq)	1.7501E-24	1.7626E-24	-23.754
Pb(OH)3-	2.6328E-28	2.232E-28	-27.651
Pb(SO4)2-2	6.5911E-24	3.4045E-24	-23.468
Pb+2	2.679E-21	1.3838E-21	-20.859
Pb2OH+3	4.2679E-41	9.6533E-42	-41.015
Pb3(OH)4+2	1.6606E-58	8.5776E-59	-58.067
Pb4(OH)4+4	1.6675E-75	1.187E-76	-75.926
PbBr+	1.2672E-24	1.0743E-24	-23.969
PbBr2 (aq)	1.3124E-28	1.3218E-28	-27.879
PbBr3-	6.2082E-33	5.263E-33	-32.279
PbCl+	5.1485E-22	4.3647E-22	-21.36
PbCl2 (aq)	8.2364E-24	8.2954E-24	-23.081
PbCl3-	6.7523E-26	5.7243E-26	-25.242
PbCl4-2	3.6603E-28	1.8907E-28	-27.723
PbCO3 (aq)	1.9874E-22	2.0017E-22	-21.699
PbF+	1.9766E-23	1.6757E-23	-22.776
PbF2 (aq)	1.7547E-26	1.7673E-26	-25.753
PbH2PO4+	1.0321E-23	8.7494E-24	-23.058
PbHCO3+	9.3998E-23	7.9688E-23	-22.099
PbHPO4 (aq)	2.7598E-22	2.7796E-22	-21.556
PbOH+	5.192E-22	4.4016E-22	-21.356
PbSO4 (aq)	6.1441E-22	6.1881E-22	-21.208
PO4-3	3.745E-09	8.4706E-10	-9.072
SO4-2	0.0017677	0.00091304	-3.04

Visual Minteq run with 10mg of lead and plastic adsorption surface added:

	Concentration	Activity	Log activity
ads-Pb-PVC	0.000048269	0.000048269	-4.316
Br-1	0.000018272	0.00001549	-4.81
Ca(NH3)2+2	4.363E-14	2.2536E-14	-13.647
Ca+2	0.00043013	0.00022217	-3.653
CaCl+	5.7159E-06	4.8458E-06	-5.315
CaCO3 (aq)	1.5628E-08	1.574E-08	-7.803
CaF+	3.0902E-07	2.6197E-07	-6.582
CaH2PO4+	0.000001141	9.6732E-07	-6.014
CaHCO3+	2.414E-07	2.0465E-07	-6.689
CaHPO4 (aq)	0.000015648	0.000015761	-4.802
CaNH3+2	7.7927E-09	4.0252E-09	-8.395
CaOH+	6.6216E-10	5.6135E-10	-9.251
CaPO4-	6.2273E-07	5.2792E-07	-6.277
CaSO4 (aq)	0.000045171	0.000045494	-4.342
Cl-1	0.010242	0.008683	-2.061
CO3-2	8.2648E-08	4.269E-08	-7.37
F-1	0.00010076	0.000085421	-4.068
Fe(NH3)2+2	2.7164E-14	1.4031E-14	-13.853
Fe(NH3)3+2	8.3578E-19	4.317E-19	-18.365
Fe(NH3)4+2	1.0969E-23	5.666E-24	-23.247
Fe(OH)2 (aq)	3.1109E-13	3.1332E-13	-12.504
Fe(OH)3-	1.48E-16	1.2547E-16	-15.901
Fe+2	1.1962E-06	6.1788E-07	-6.209
FeCl+	3.993E-09	3.3851E-09	-8.47
FeF+	1.0097E-09	8.56E-10	-9.068
FeH2PO4+	7.1042E-08	6.0226E-08	-7.22
FeHCO3+	6.6368E-10	5.6264E-10	-9.25
FeHPO4 (aq)	3.7904E-07	3.8176E-07	-6.418
FeNH3+2	3.4348E-10	1.7742E-10	-9.751
FeOH+	3.6743E-09	3.1149E-09	-8.507
FeSO4 (aq)	1.3461E-07	1.3557E-07	-6.868
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00022941	0.00019448	-3.711
H3PO4	2.1567E-09	2.1721E-09	-8.663
HCO3-	0.00008532	0.000072331	-4.141
HF (aq)	1.0197E-08	1.027E-08	-7.988
HF2-	4.1196E-12	3.4924E-12	-11.457

	Concentration	Activity	Log activity
HPO4-2	0.00030046	0.0001552	-3.809
HSO4-	8.1845E-09	6.9385E-09	-8.159
K+1	0.000050565	0.000042867	-4.368
K2HPO4 (aq)	3.776E-12	3.8031E-12	-11.42
K2PO4-	3.2498E-16	2.7551E-16	-15.56
KCl (aq)	1.8522E-07	1.8655E-07	-6.729
KF (aq)	1.6618E-09	1.6738E-09	-8.776
KH2PO4 (aq)	1.6516E-08	1.6634E-08	-7.779
KHPO4-	5.953E-08	5.0467E-08	-7.297
KOH (aq)	9.3663E-12	9.4334E-12	-11.025
KPO4-2	1.8404E-12	9.5062E-13	-12.022
KSO4-	3.1998E-07	2.7126E-07	-6.567
Mg(NH3)2+2	2.1541E-14	1.1127E-14	-13.954
Mg+2	0.00010643	0.000054976	-4.26
Mg2CO3+2	9.7182E-13	5.0197E-13	-12.299
MgCl+	2.2417E-06	1.9004E-06	-5.721
MgCO3 (aq)	1.9382E-09	1.9521E-09	-8.709
MgF+	4.4002E-07	3.7303E-07	-6.428
MgHCO3+	4.8109E-08	4.0785E-08	-7.389
MgHPO4 (aq)	5.3451E-06	5.3834E-06	-5.269
MgOH+	3.1221E-09	2.6468E-09	-8.577
MgPO4-	2.4087E-09	2.042E-09	-8.69
MgSO4 (aq)	8.8786E-06	8.9422E-06	-5.049
Na+1	0.00086063	0.00072961	-3.137
Na2HPO4 (aq)	7.227E-10	7.2787E-10	-9.138
Na2PO4-	2.0127E-13	1.7063E-13	-12.768
NaCl (aq)	3.1525E-06	3.1751E-06	-5.498
NaCO3-	6.8413E-10	5.7998E-10	-9.237
NaF (aq)	6.4797E-08	6.5261E-08	-7.185
NaH2PO4 (aq)	2.811E-07	2.8312E-07	-6.548
NaHCO3 (aq)	2.6261E-08	2.6449E-08	-7.578
NaHPO4-	1.5693E-06	1.3304E-06	-5.876
NaOH (aq)	1.1549E-10	1.1631E-10	-9.934
NaPO4-2	3.1324E-11	1.618E-11	-10.791
NaSO4-	4.2275E-06	3.5839E-06	-5.446
NH3 (aq)	0.000011246	0.000011326	-4.946
NH4+1	0.0018613	0.0015779	-2.802
NH4SO4-	0.000017827	0.000015113	-4.821
OH-	1.4937E-07	1.2663E-07	-6.897
Pb(CO3)2-2	1.9864E-23	1.026E-23	-22.989
Pb(OH)2 (aq)	8.175E-22	8.2335E-22	-21.084
Pb(OH)3-	1.2299E-25	1.0426E-25	-24.982

	Concentration	Activity	Log activity
Pb(SO4)2-2	2.9508E-21	1.5242E-21	-20.817
Pb+2	1.2514E-18	6.464E-19	-18.189
Pb2OH+3	9.3129E-36	2.1064E-36	-35.676
Pb3(OH)4+2	1.6927E-50	8.7432E-51	-50.058
Pb4(OH)4+4	7.9396E-65	5.6516E-66	-65.248
PbBr+	5.9195E-22	5.0183E-22	-21.299
PbBr2 (aq)	6.1308E-26	6.1747E-26	-25.209
PbBr3-	2.9E-30	2.4585E-30	-29.609
PbCl+	2.4038E-19	2.0378E-19	-18.691
PbCl2 (aq)	3.8436E-21	3.8712E-21	-20.412
PbCl3-	3.1495E-23	2.67E-23	-22.573
PbCl4-2	1.7064E-25	8.8141E-26	-25.055
PbCO3 (aq)	9.2838E-20	9.3503E-20	-19.029
PbF+	9.2001E-21	7.7995E-21	-20.108
PbF2 (aq)	8.1382E-24	8.1965E-24	-23.086
PbH2PO4+	4.6893E-21	3.9754E-21	-20.401
PbHCO3+	4.3909E-20	3.7224E-20	-19.429
PbHPO4 (aq)	1.254E-19	1.2629E-19	-18.899
PbOH+	2.4253E-19	2.0561E-19	-18.687
PbSO4 (aq)	2.8097E-19	2.8299E-19	-18.548
PO4-3	3.6427E-09	8.2391E-10	-9.084
SO4-2	0.0017305	0.00089385	-3.049

Visual Minteq run with 10mg of lead added:

	Concentration	Activity	Log activity
Br-1	0.00001826	0.00001548	-4.81
Ca(NH3)2+2	4.3656E-14	2.2549E-14	-13.647
Ca+2	0.00043035	0.00022229	-3.653
CaCl+	5.7161E-06	4.8459E-06	-5.315
CaCO3 (aq)	1.5637E-08	1.5749E-08	-7.803
CaF+	3.0859E-07	2.6161E-07	-6.582
CaH2PO4+	0.000001136	9.6309E-07	-6.016
CaHCO3+	2.4153E-07	2.0476E-07	-6.689
CaHPO4 (aq)	0.00001558	0.000015692	-4.804
CaNH3+2	7.7971E-09	4.0274E-09	-8.395
CaOH+	6.625E-10	5.6164E-10	-9.251
CaPO4-	0.00000062	5.2561E-07	-6.279
CaSO4 (aq)	0.000045045	0.000045368	-4.343
Cl-1	0.010237	0.0086786	-2.062
CO3-2	8.2648E-08	4.269E-08	-7.37

	Concentration	Activity	Log activity
F-1	0.00010057	0.000085259	-4.069
Fe(NH3)2+2	2.7209E-14	1.4054E-14	-13.852
Fe(NH3)3+2	8.3718E-19	4.3242E-19	-18.364
Fe(NH3)4+2	1.0988E-23	5.6757E-24	-23.246
Fe(OH)2 (aq)	3.1158E-13	3.1381E-13	-12.503
Fe(OH)3-	1.4823E-16	1.2566E-16	-15.901
Fe+2	1.1981E-06	6.1885E-07	-6.208
FeCl+	3.9973E-09	3.3887E-09	-8.47
FeF+	1.0094E-09	8.5571E-10	-9.068
FeH2PO4+	7.0804E-08	6.0025E-08	-7.222
FeHCO3+	6.6472E-10	5.6352E-10	-9.249
FeHPO4 (aq)	3.7777E-07	3.8048E-07	-6.42
FeNH3+2	3.4403E-10	1.777E-10	-9.75
FeOH+	3.68E-09	3.1198E-09	-8.506
FeSO4 (aq)	1.3437E-07	1.3534E-07	-6.869
H+1	9.3697E-08	7.9433E-08	-7.1
H2CO3* (aq)	0.00001283	0.000012922	-4.889
H2PO4-	0.00022828	0.00019353	-3.713
H3PO4	2.1461E-09	2.1615E-09	-8.665
HCO3-	0.00008532	0.000072331	-4.141
HF (aq)	1.0177E-08	1.025E-08	-7.989
HF2-	4.104E-12	3.4792E-12	-11.459
HPO4-2	0.00029899	0.00015444	-3.811
HSO4-	8.1575E-09	6.9156E-09	-8.16
K+1	0.000050567	0.000042869	-4.368
K2HPO4 (aq)	3.7578E-12	3.7847E-12	-11.422
K2PO4-	3.2341E-16	2.7418E-16	-15.562
KCl (aq)	1.8514E-07	1.8646E-07	-6.729
KF (aq)	1.6588E-09	1.6706E-09	-8.777
KH2PO4 (aq)	1.6436E-08	1.6553E-08	-7.781
KHPO4-	5.924E-08	5.0221E-08	-7.299
KOH (aq)	9.3667E-12	9.4338E-12	-11.025
KPO4-2	1.8315E-12	9.46E-13	-12.024
KSO4-	3.1893E-07	2.7038E-07	-6.568
Mg(NH3)2+2	2.1554E-14	1.1133E-14	-13.953
Mg+2	0.00010649	0.000055005	-4.26
Mg2CO3+2	9.7282E-13	5.0249E-13	-12.299
MgCl+	2.2417E-06	1.9004E-06	-5.721
MgCO3 (aq)	1.9392E-09	1.9531E-09	-8.709
MgF+	4.3941E-07	3.7251E-07	-6.429
MgHCO3+	4.8134E-08	4.0806E-08	-7.389
MgHPO4 (aq)	5.3217E-06	5.3598E-06	-5.271

	Concentration	Activity	Log activity
MgOH+	3.1237E-09	2.6481E-09	-8.577
MgPO4-	2.3981E-09	2.033E-09	-8.692
MgSO4 (aq)	8.8538E-06	8.9172E-06	-5.05
Na+1	0.00086066	0.00072963	-3.137
Na2HPO4 (aq)	7.1921E-10	7.2436E-10	-9.14
Na2PO4-	2.003E-13	1.6981E-13	-12.77
NaCl (aq)	3.1511E-06	3.1736E-06	-5.498
NaCO3-	6.8416E-10	5.8E-10	-9.237
NaF (aq)	6.4676E-08	6.5139E-08	-7.186
NaH2PO4 (aq)	2.7974E-07	2.8174E-07	-6.55
NaHCO3 (aq)	2.6262E-08	2.645E-08	-7.578
NaHPO4-	1.5616E-06	1.3239E-06	-5.878
NaOH (aq)	1.1549E-10	1.1632E-10	-9.934
NaPO4-2	3.1171E-11	1.6101E-11	-10.793
NaSO4-	4.2137E-06	3.5722E-06	-5.447
NH3 (aq)	0.000011246	0.000011327	-4.946
NH4+1	0.0018614	0.001578	-2.802
NH4SO4-	0.000017769	0.000015064	-4.822
OH-	1.4937E-07	1.2663E-07	-6.897
Pb(CO3)2-2	4.1718E-10	2.1548E-10	-9.667
Pb(OH)2 (aq)	1.7169E-08	1.7292E-08	-7.762
Pb(OH)3-	2.583E-12	2.1897E-12	-11.66
Pb(SO4)2-2	6.1565E-08	3.18E-08	-7.498
Pb+2	0.000026283	0.000013576	-4.867
Pb2OH+3	4.1079E-09	9.2913E-10	-9.032
Pb3(OH)4+2	1.5681E-10	8.0997E-11	-10.092
Pb4(OH)4+4	1.5448E-11	1.0996E-12	-11.959
PbBr+	1.2424E-08	1.0532E-08	-7.977
PbBr2 (aq)	1.2859E-12	1.2951E-12	-11.888
PbBr3-	6.0783E-17	5.153E-17	-16.288
PbCl+	0.000005046	4.2778E-06	-5.369
PbCl2 (aq)	8.0644E-08	8.1221E-08	-7.09
PbCl3-	6.6046E-10	5.5991E-10	-9.252
PbCl4-2	3.5767E-12	1.8474E-12	-11.733
PbCO3 (aq)	1.9498E-06	1.9638E-06	-5.707
PbF+	1.9286E-07	1.635E-07	-6.786
PbF2 (aq)	1.7027E-10	1.7149E-10	-9.766
PbH2PO4+	9.8003E-08	8.3083E-08	-7.08
PbHCO3+	9.2219E-07	7.8179E-07	-6.107
PbHPO4 (aq)	2.6207E-06	2.6395E-06	-5.578
PbOH+	5.0937E-06	4.3183E-06	-5.365
PbSO4 (aq)	5.8816E-06	5.9237E-06	-5.227

	Concentration	Activity	Log activity
PO4-3	3.6248E-09	8.1987E-10	-9.086
SO4-2	0.0017248	0.0008909	-3.05

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